A GUIDEBOOK TO ELECTRICITY

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To

A. B. S.

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PREFACE

THIS book is presented to the reader with all possible humility; because to attempt—in a single volume, however large—to write a guide to such an omnipresent influence as electrical energy is to undertake a task which at first sight appears almost hopeless. Nevertheless it may be thought that some guidance is better than none, and so the book has been written.

It is not, of course, intended for professional electrical engineers, or even students, but instead is meant for the layman interested in electrical matters and perhaps also for those who—engaged in the other engineering arts—may need some slight acquaintance with electricity. The author freely admits that in the interests of simplification certain liberties have been taken with those aspects of the subject where only a technical training could have enabled the reader to follow the academic reasoning necessary for a fully scientific explanation.

Here, then, is a guidebook which can only hope to whisk the reader along the main trunk roads: but at least it may perhaps show him something of the extent of the fascinating country and its innumerable by-roads along which he may travel at his own leisure.

The Author wishes to acknowledge, with many thanks, the help afforded to him by those Companies and Organizations who provided him with photographic illustrations. Each photograph is acknowledged individually. He would also like to thank his secretary, Mrs. Margaret Hunt, for her painstaking assistance, and her husband, Dalton Hunt, for his work on the drawings which illustrate the text.

J. H. M. SYKES.

Bedford
March 1955

CHAPTER I

BASIC PRINCIPLES

To UNDERSTAND as much as we know at present about electrical energy, it is necessary first to take a brief glance inside the atom. Atoms are the bricks of which all matter is made; and until recently they were regarded as the smallest unit into which one could sub-divide a pure material. The working "picture" of the atom we nowadays use shows it as consisting of a miniature solar system, just like the sun and the planets. In the centre is a nucleus, and revolving round it are electrons as the planets revolve round the sun, or as the moon revolves round the earth. The electrons continue to revolve round their "sun" for the same reason that the planets revolve round the real sun; they do not fly off into free space because there is an attractive force between the nucleus and the electrons.

In the case of certain materials the electrons farthest from the nucleus are only held into their orbits by a bond which is relatively weak, and they can be detached by the application of suitable forces from outside.

If we now come to the practical consideration of how these theories are applied to a piece of ordinary copper wire, we must envisage first all the atoms, of pure copper, jammed closely together but in reality consisting of small solar systems. If, at one end of the wire (Fig. I, 1), we can apply a force to what (by a stretch of imagination) we can regard as the first atom in the wire, we can detach an electron from it which will career off amongst the other atoms, in doing so it will knock another electron away from another atom—whichever one it strikes first—because the nucleus is only powerful enough to hold its proper number of electrons, and if one is added another one must leave.

This exchange of electrons takes place all along the wire, and it happens at the same speed as that of light—186,000 miles a second.

Thus, in what amounts to a negligible time interval, the force we have applied at one end of the wire has been transmitted throughout, and it results in a free electron apparently being made available at the other end. In practice, this process must operate in a circle since the *complete* liberation of an electron is equivalent to altering or even breaking up the atom; and this is the sort of operation that could only be undertaken if enormous force is available, such as the power necessary when nuclear fission is carried out in a research laboratory. The wire must be made up in the form of a complete circuit, so that the electrons can be made to circulate round without ever leaving the closed ring.

This circulation of electrons is, in fact, the electric current. Electricity is a form of energy, and when we cause an electric current to flow

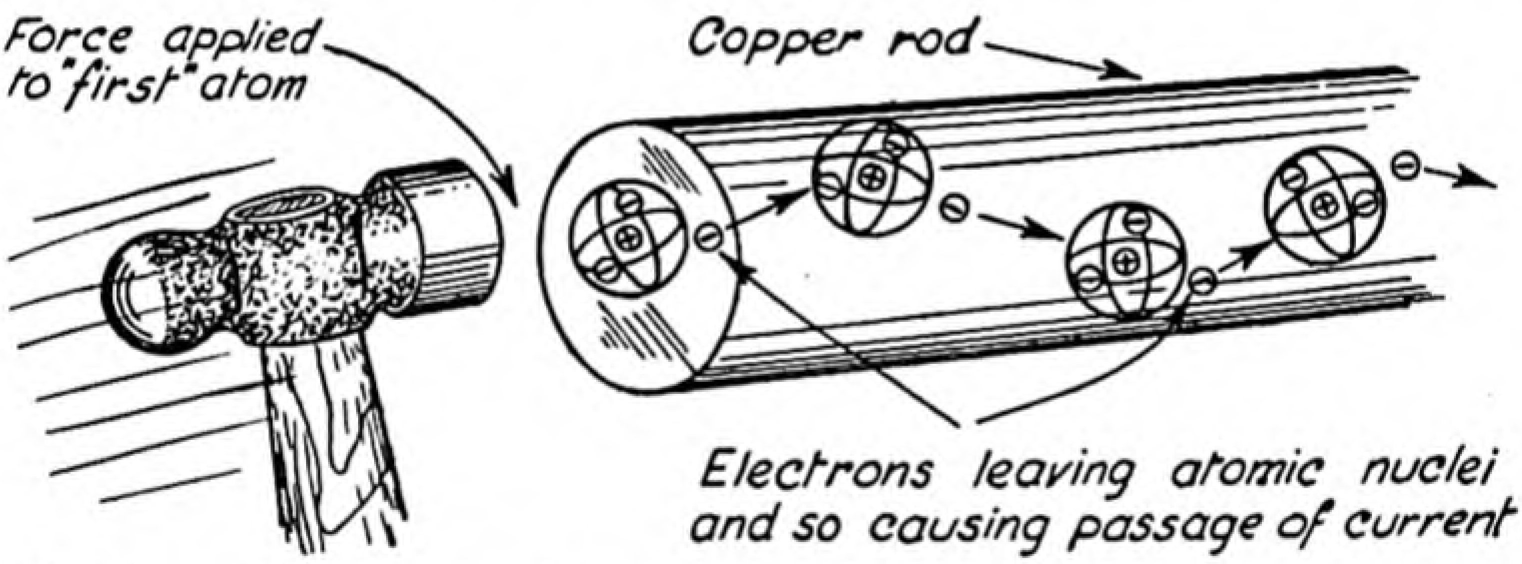

Fig. I, 1.—Diagrammatic representation of the conventional theory of the passage of an electric current through a copper wire

in a circuit, what we are really doing is to transform one kind of energy into another. As mentioned above, the operation of detaching one electron from the "first" copper atom had to be carried out by the application of force; an electric current resulted, which meant that the force applied—in this simple instance, a mechanical force—was transformed into an electric current.

In practice there are a number of ways in which an electric current can be established.

Generation of Current

The most commonly used is the electro-magnetic method, by which all the power used for our heat, light and industry is generated. In 1831 Michael Faraday, working in the Royal Institution in London, found that when a loop of wire was revolved between the poles of a magnet an electric current began to flow. The magnetic force had

caused the electrons to be detached from the nuclei of the atoms in the wire (though Faraday did not realize this), and the energy used by the operator in turning the loop of wire working against this magnetic force was thus transformed into electrical energy. From this simple experiment the dynamo was developed; and now, in the power stations of the world, the enormous amounts of electrical energy that are being generated every minute are created by the transformation of the mechanical force in the water-wheel, the steam turbine, or the diesel engine, into electrical energy, by turning a large number of loops of wire in the presence of magnetic fields. There has been no change in the basic principle, although there has been very great development and refinement in the way in which it is applied.

The second way to generate electrical energy, which was actually discovered before Faraday's important researches, is the electro-chemical method. If two different metals are placed in a jar of acid, so that they do not touch, and then an external wire is connected between the two, a current will flow. This transformation of energy is caused by the fact that chemical reactions often set up, in effect, the same kind of "electron transfer" as in the simple example given above of the mechanical force at one end of a wire causing electrons to fly off and traverse the whole length of the circuit.

This electro-chemical process forms the basis of the primary batteries, used by the million every day in our torches and cycle lamps, and for the "high tension" batteries for portable radio receivers. It is too expensive and too cumbersome a method of generating electrical energy to use on a large scale; but it is very important since it makes possible the provision of a portable source of electrical energy in a convenient fashion.

There are several other methods of generating electrical energy, but they are not used for large-scale generation although they have important applications for special purposes. One of them is the use of the thermo-electric effect. If two suitable metals are joined together in such a way that there is a chain of alternate pieces, first of one metal and then of the other, and the alternate junctions are heated (the others being kept cool), a current will flow if a wire links the two ends of the chain. This thermo-electric effect is due to the application of energy in yet another form—heat. The speed with which the electrons fly round their orbits around the nucleus in each atom is related to temperature. If the temperature is greatly increased, they begin to fly round so rapidly that eventually one of them flies off altogether, by a kind of centrifugal force, and so sets up the electric current as before.

We can now begin to examine the practical applications of these

theoretical considerations. First, it will be realized that some form of electrical generator is needed to create a current. For the moment we will imagine that this is a box having two terminals. (Later we will examine what the box contains.) If the generator is in working order, we can assume, from what has been mentioned previously, that if we join a wire between the terminals a current will flow. Thus there exists, between these terminals, a potential; or, as it is commonly called, *an electromotive force*, or pressure. This is measured in volts.

The Flow of Current

An analogy, from another field of energy transformation, is to consider a pipe running down a hill. Somewhere in the pipe is a water-wheel, which will turn when water flows (Fig. I, 2). If we now carry a bucket of water to the top of the hill (thus expending energy) we create a potential since having carried the water to the top it will, if we pour it in, flow down the pipe. In doing so, the energy we have put in to the operation of carrying the water up the hill can be returned to us in another form by the operation of the water-wheel, as it grinds corn or carries out some other form of work. Obviously, the higher the hill the greater the force in the water; and the height of the hill is equivalent to the voltage (or pressure) in the electric circuit. The flow of water—the amount of water per minute—is equivalent to the current.

If we want to transport a given quantity of water from one place to another through a pipe we can do it in one of two ways. We can employ a high pressure, so that there is a swift flow through the pipe, and we can get, say, a thousand gallons an hour into the tank at the far end. On the other hand we can use a larger pipe and a lower pressure so that we still get a thousand gallons in the same time. In electrical terms, the "flow" is called the current (measured in amperes), and as we have seen above, the pressure is equivalent to the electromotive force, measured in volts. In the electrical case, the speed of flow is fixed, but the number of atoms from which electrons are detached varies according to the amount of "force" applied to the conductor. The greater the force, or voltage, the greater the current through a given wire.

To carry out a particular task by means of electrical energy we can use a high voltage so arranged as to produce a small current, or we can use a low voltage arranged to produce a large current. We shall see later that this is of great importance in connection with the transmission of electric power over long distances.

In the elementary electrical circuit which we have been considering

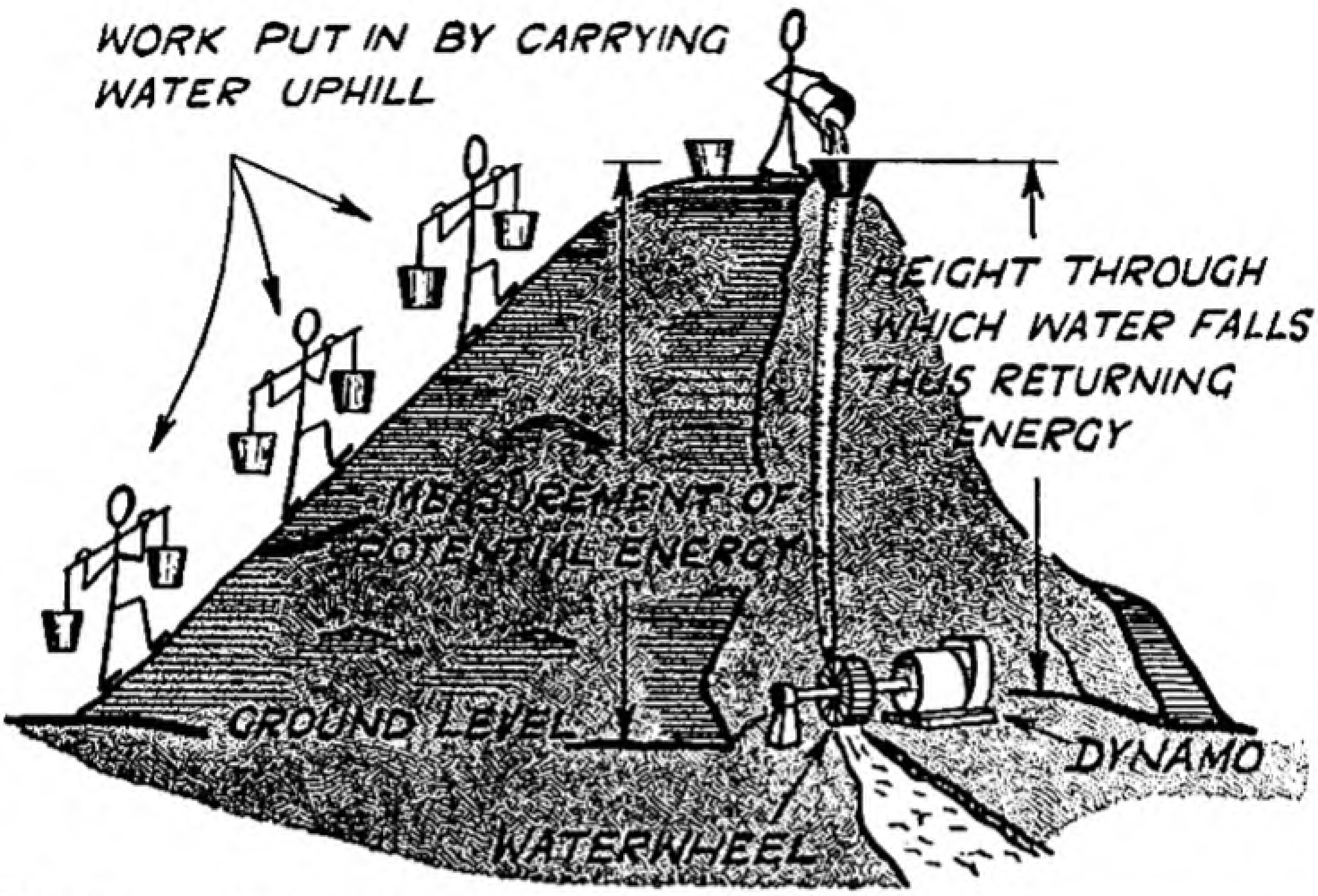

Fig. I, 2.—Analogy between water flow and flow of electric current

so far there is a third factor to be taken into account. The electrons that are released from the atoms, and that make up the electric current, can be detached more easily from the atoms of certain kinds of substances than from those of others, and the electron transfer along the wire is thus more easily accomplished. The materials in which electron transfer is easy are called conductors, and the best-known examples are copper and aluminium. Platinum, gold and silver are very good conductors, and iron is also a useful conductor, although not so good as copper.

Other materials, such as wood or glass, are not very good conductors. This means that it is almost impossible to wrench away electrons from the atoms of which they are composed (to be scientifically accurate, the materials just mentioned are not simple materials, containing only one substance, such as copper, but are made up of complicated molecules in which the atoms are rigidly tied up in frameworks or lattices, so that the release of electrons is made more difficult). These materials are called insulators, because in general they do not permit the passage of an electric current.

The most commonly used insulators, in ordinary electrical engineering practice, are rubber, porcelain and the many plastic materials now available for insulation purposes.

In recent years there has been much research into the properties of certain materials which are known as semi-conductors. These materials,

of which some germanium and silicon crystals are typical, allow current to flow much more freely in one direction than in the other. They are used mainly for rectifying alternating current into direct current.

We have seen that the flow of current through various materials varies with the ease with which it is possible to detach the electrons from the atoms. Even among conductors there is a considerable variation, and the measurement applied to this quality is known as the value of the resistance. In the case of the water flowing down the hill through the pipe, it is useful to imagine—to gain some idea of the effect of resistance—that the pipe, instead of being clear, is filled with porous material; and if this material is very tightly packed the flow of water will be obstructed and greater pressure will be needed to force a given volume of water through in a given time. If the material is not so tightly packed, there will be less resistance to the flow.

In the electrical case, the resistance, due (as mentioned above) to the differing properties of different materials in regard to the freeing of the electrons from the atoms, is measured in ohms.

Thus we have three basic quantities concerned in a simple direct current electrical circuit—the electromotive force available at the generator to start pushing the current through the wire; the resistance encountered *en route*; and the consequent flow of current. These three quantities are connected by what is known as Ohm's Law. This extremely simple expression is one which every electrician must know; and in fact it has been said with more than a little truth that the whole of electrical engineering is "Ohm's Law and common sense".

Ohm's Law states that the current in any circuit is directly proportional to the voltage and inversely proportional to the resistance. It is expressed in the following way:

$$\text{Current (in amperes)} = \frac{\text{Electromotive force (in volts)}}{\text{Resistance (in ohms)}}$$

This is a perfectly logical deduction from the arguments we have discussed above: the greater the pressure, the greater the current; the greater the resistance, the less the current. To take a simple numerical example, let us consider a battery—for example, the battery on a motor-car. At the terminals it is capable of delivering 12 volts. Supposing we now connect across these terminals a piece of wire having a resistance of six ohms. What current will flow? We can work it out very simply from Ohm's Law.

$$\text{Current} = \frac{12}{6} = 2 \text{ amperes}$$

Now suppose that the wire was taken away, and a fresh wire—this time with a resistance of, say, 300 ohms—was substituted. Again we should have

$$\text{Current} = \frac{12}{300} = \frac{1}{25}\text{th part of an ampere}$$

Ohm's Law may be used in another way. Supposing we know the current we want, and we know the resistance of the wire. How much voltage will be needed to create that current? By the very simplest of simple mathematics, we switch the formula round so that it reads:

$$\text{Electromotive force} = \text{Current} \times \text{Resistance.}$$

We want a current of 10 amperes in a wire having a resistance of 100 ohms. Then, $10 \times 100 = 1{,}000$ volts.

Finally, we can rearrange the formula for Ohm's Law once again, so that it reads

$$\text{Resistance} = \frac{\text{Electromotive force}}{\text{Current}}$$

In this way we can find the resistance of a wire in which we know a particular current is flowing, and where we know the voltage which creates it. Supposing we measure a current of 20 amperes in a wire to which an electromotive force of 100 volts is applied; then

$$\text{Resistance} = \frac{100}{20} = 5 \text{ ohms}$$

It cannot be stressed too strongly that anyone who wishes to become acquainted with the basic elements on which all electrical engineering is built must thoroughly understand the implications of Ohm's Law. The symbol normally used for current is I, with E (electromotive force) for the voltage, and R for the resistance. The Law then reads:

$$I = \frac{E}{R}$$

There are one or two further theoretical points to clear up at this stage. First we must go back for a moment to the three basic units—the ampere, the volt and the ohm. These are legally defined, the volt being a certain proportion of the electromotive force produced by a

standard primary battery kept in the National Physical Laboratory, and the current being defined by reference to its electro-chemical effects. When we pass a current through a liquid (as we shall see later) certain effects take place, and among them is the depositing of metal on one of the poles at a rate depending on the current flowing. A standard has been set up to define the ampere in this way. The ohm is also legally defined as the resistance of a particular bar of platinum, kept—like the standard yard measure and the pound weight—in a National laboratory.

In practice (from Ohm's Law) one volt will cause a current of one ampere to flow in a circuit having a resistance of one ohm. To give a better idea of the pressure represented by a volt, some voltage values commonly encountered may be cited. The voltage of a flash-lamp battery is about 2 volts; the ordinary domestic voltage at which our lamps and radio sets are supplied is 240 volts (although there are a few systems still operating at 110 volts, and some at 200 or 220 volts, which have not yet been converted to the national 240-volt standard in Great Britain). The voltage used on most parts of the National Grid in Great Britain is 132,000 volts, while there is a Super-Grid operating at 275,000 volts. The highest voltage used for commercial electricity supply anywhere in the world is in Sweden, where the long-distance transmission lines operate at 380,000 volts.

Turning to typical values of current, the ordinary one-bar radiator, operating on the domestic voltage of 240 volts, takes a current of 4·17 amperes. For driving an electric train a current of 6,000 amperes may be required at starting, and for electrolysis of brine, to manufacture chlorine for chemical purposes, as much as 100,000 amperes may be required.

To indicate a resistance value applicable to an item of electrical equipment commonly employed, the resistance of the wire filament of an ordinary 100-watt electric lamp, for a 240-volt circuit, is 576 ohms. The resistance of the copper conductors in the cables carrying the current from the power station to a residence half a mile away will be no greater than the 100th part of an ohm.

POWER

The next theoretical concept that we must make clear is that of power. Power is the rate of doing work, and is measured, in mechanical terms, by horsepower. Bearing in mind, from the first principles stated earlier in this chapter, that electricity is really a form of energy, it will be realized that if a horse were harnessed to a rope which was coupled

to a treadmill driving a dynamo, there would be an amount of electrical energy generated in a given time which was exactly equivalent to the power exerted by the horse. Thus there is a relationship between horsepower and electrical energy: and 746 watts—the watt being the unit used for measuring electrical power—are equivalent to one horsepower. (The term horsepower is here used in the scientific sense: an actual carthorse might for a short time exert considerably more power than 1 h.p.)

Obviously, in a particular case of transmitting energy, if the pressure (whether of water or electricity) is increased, the power delivered in a given time with the same flow will also be increased; and—equally obviously—if the pressure remains constant, and the flow is increased, more power will again be delivered in a given time. If we consider this mathematically, we have the very simple formula that Watts $=$ Volts $\times$ Amperes.

By stating the wattage, we can specify what power a generator can give out. If it is, for example, a generator with an electromotive force of 100 volts, and it can cause a current of 2 amperes to flow, then from the formula its power rating is 100 (volts) $\times$ 2 (amperes) $=$ 200 watts. This is equivalent to saying that the strength of the "blow" it can continuously deliver to the atoms at the "front" end of the wire is such that a number of electrons equivalent to the passage of 2 amperes of current will be freed from these atoms, and will traverse the conductor.

Energy

Energy is the capacity of doing work. If the power is delivered from a mechanical machine, such as a steam locomotive, or an electrical generator, for two hours, obviously a greater amount of energy will be delivered than if it had been operating for one hour. Thus, to measure the energy delivered we must bring the time factor into consideration, and the electrical unit used to measure energy is the watt-hour. If a generator delivers one watt of power for one hour, it will have transformed one watt-hour of energy from the originating source—which may have been mechanical or chemical—into electrical energy.

In practice, the watt is too small a unit for commercial use, and the most commonly used unit is 1,000 watts, which is known as a kilowatt; and the unit of energy is the kilowatt-hour, written kWh. One kilowatt-hour is also known as one Board of Trade Unit, since it forms the legal unit for the supply of electrical energy to the consumer.

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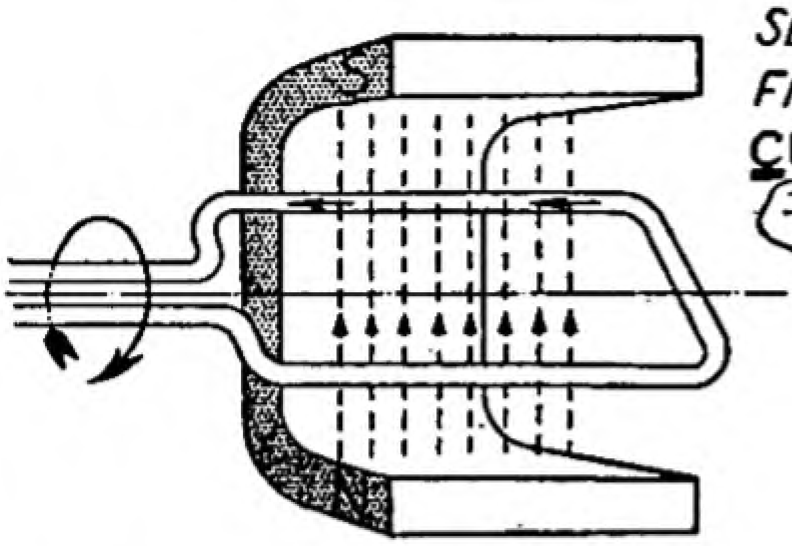
CHAPTER II

PRIME MOVERS

As WE have seen, to generate power on a commercial scale it is necessary to have a loop of wire which is revolved in a magnetic field—the method originally evolved by Faraday. If the very simplest form of electrical generator is imagined, it will take the form of a loop of wire secured to two rings mounted on a shaft, the whole assembly revolving between the poles of a permanent magnet, where the magnetic field exists. It will be helpful to consider this magnetic field as if it consisted of a very large number of thin threads, running from the north pole to the south pole of the magnet. As the loop of wire revolves in this field, it is said to "cut" the lines of magnetic force—the threads. The faster it cuts them, the more electromotive force will be generated (Fig. II, 1).

There is a very simple rule governing the way in which this generating action takes place, called the "right-hand rule". (It is easy to remember, because with the simplest toy generator, turned by a handle, one normally uses one's *right* hand to generate current.) The forefinger, the thumb, and the second finger are extended, all at right angles to each other. If the *F*orefinger is pointed in the direction of the *F*ield (from north pole to south pole), and the thu*M*b is pointed in the direction of *M*otion of the portion of wire under consideration, the se*C*ond finger will give the direction of *C*urrent which will flow (Fig. II, 2).

Using this rule, with our elementary generator, we see that when the left-hand side of the loop is moving *up*wards, the current will be in the direction away from the handle. Thus the current will flow *out* of a collector-ring connected to the right-hand side of the loop. Now let us imagine that the loop is turned through half a circle. The side of the loop we were considering before has now reached the right-hand side, and if we apply the right-hand rule once more, we see



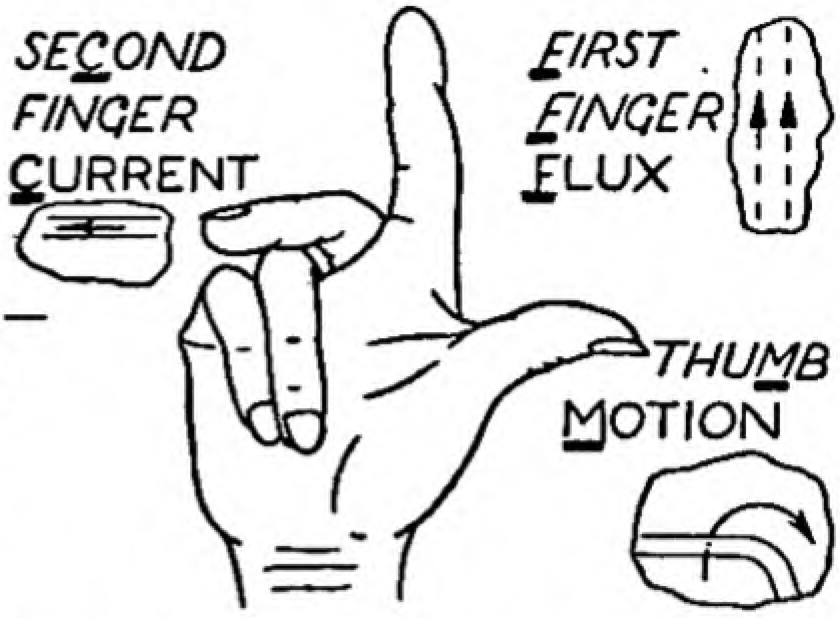


Fig. II, 1.—Electromotive force generated by rotating a coil in the field of a magnet

Fig. II, 2.—The "right-hand rule", to find the direction of the current generated

that the current will now flow the other way. Again, we should remember that the faster the wire cuts the lines of force between the poles, the greater the electromotive force (and the more current, if the loop is closed through an external circuit) which will be set up. In the position where the loop is horizontal, the sides are cutting the maximum number of lines of force, or threads, for each degree turned; but when the loop has turned through a quarter of a circle, at that instant it is not *cutting* any lines of force at all—it is running parallel to them. So at that instant no electromotive force at all is being generated.

Alternating Current

It is now possible to see how the familiar phrase "alternating current" arises. If we follow the progress, round the circle, of one side of the loop of wire being revolved between the poles of a magnet, we shall find the following events occurring. First, if we start at the "top" of the circle, the wire will not be cutting any lines of force; no voltage is being generated. Then, as we start to go round clockwise, in the first quarter-circle, the wire will begin to cut more and more "threads" for each degree of movement. A voltage will be generated in one direction (given by the right-hand rule) and we will call this voltage "positive". It will reach its maximum when the loop is horizontal; and as the wire continues downwards, the number of "threads" of force cut for each degree will decrease, and so the voltage will decrease, until the positive voltage reaches zero again at the "bottom" of the circle. As the wire continues on its passage, it will now go upwards and commence to cut the lines of force in the opposite direction; this will

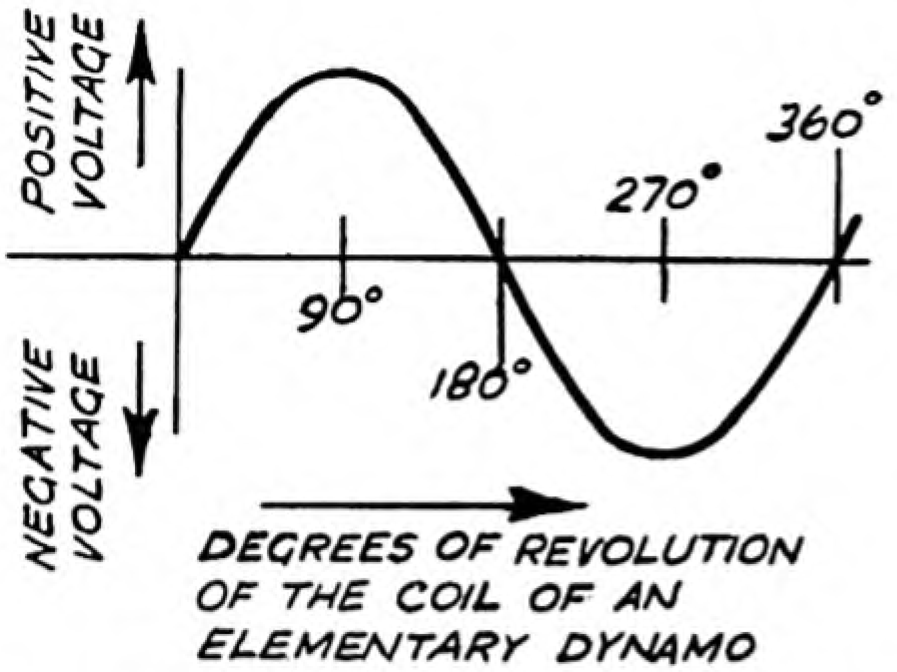


Fig. II, 3.—The alternating current cycle

generate a voltage in the other direction. This negative voltage will follow the same waxing and waning cycle; and when the element of wire has reached the "top" of the circle again, the voltage will have died down to zero (Fig. II, 3).

Thus, in a complete circular movement of the loop, there has been a rise to maximum positive from zero, a fall again to zero, and rise to maximum negative, falling again to zero ready to start all over again. This is the alternating current *cycle*; in normal supply systems such as most of those in Great Britain, there are 50 complete cycles a second.

Direct Current

The early electrical engineers felt that direct current—current in which the flow is always in the same direction—was better than alternating current, and so one of the first things they did was to evolve a method of changing the alternating current generated by the loop of wire revolving in the magnetic field into direct current. This may be done by using a device known as a commutator.

The ends of the coil, on our first generator, would have been connected to two circular rings on its shaft, to collect the current from the loop as it revolved. On these rings were brushes or carbon pieces which rested on the smooth rotating ring and made an electrical connection to the external circuit. In place of these rings, the two ends of the loop may be connected to two semi-circular metal parts, mounted on the shaft one above the other, but not touching. Two brushes are arranged so that they are diametrically opposite, and bear on these two half-circles. For clarity, let us call one brush A and the other B (Fig. II, 4). As the loop goes round, the left-hand side wire-end will be connected alternately to brush A and to brush B. As we have seen, the voltage generated by the cutting of the lines of force changes in direction, half-way round the revolution. If now the wire-ends are so connected that the half-loops of metal change from brush A to brush B at the moment when the voltage changes in direction, the voltage appearing at the brushes will always be in the *same* direction; and by

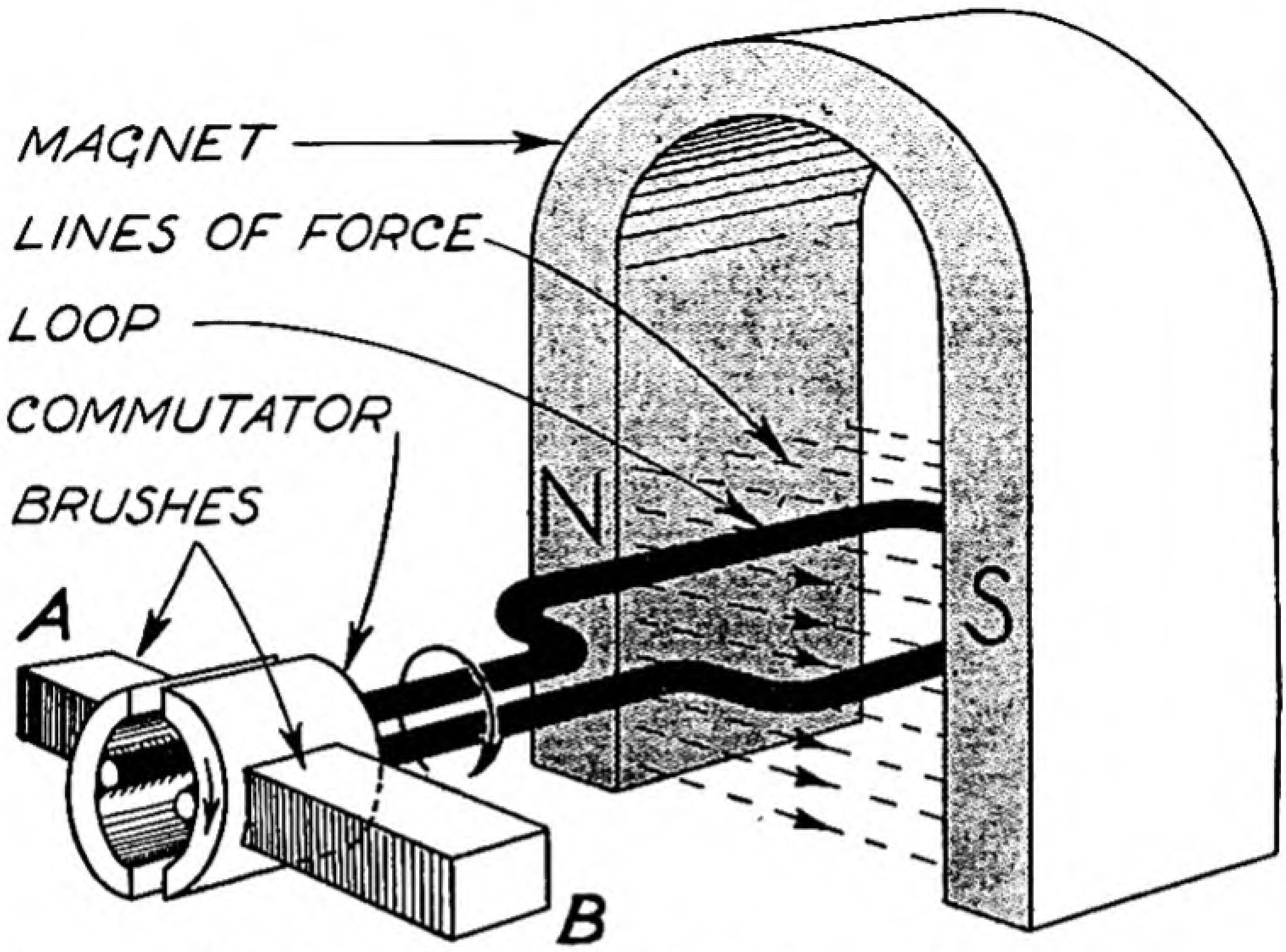


Fig. II, 4.—The principle of the commutator

applying the right-hand rule, we can soon determine if brush A is going to be positive or negative.

A simple direct current generator like this will thus generate two impulses of uni-directional voltage in each revolution, since the alternating current "wave" shape is simply altered so that both the half-loops, as they are called, are positive. Suppose now that there are a number of additional wire coils on the same shaft, all revolving together and cutting the same magnetic field. As each one passes through the phases leading to its maximum and minimum points, it will provide another direct current impulse. Each coil is connected to the commutator, which consists of a large number of segments, two for the ends of each coil of wire. Instead of a rather irregular voltage output, the output will be smoothed, as the impulses overlap, and the same sort of continuous direct current as we get from a battery, where there is no up-and-down change in voltage, will begin to appear (Fig. II, 5).

The word "generator" includes all forms of apparatus for generating electrical voltages. In practice, the direct current generator used to be called a "dynamo" but is now commonly called a "direct current generator" or just a "generator", while an alternating current generator is called an "alternator".

The practical form in which these generators is made up is

somewhat different from the simple example we have used, above, to explain the basic principle on which they all operate.

Dealing with direct current generators first, it is usual to have a magnetic field which is provided not by a permanent magnet but by an electromagnet, known as a field coil. We have seen, in Chapter I, that when a coil of wire is moved in a magnetic field, a voltage is generated. What might be regarded as the reverse effect is also true. When a current passes through a coil of wire, the coil becomes a magnet, and (as iron allows the passage of magnetic lines of force much more easily than air) if we enclose a core of iron in a coil, and then pass current through the coil, we have the equivalent of a bar magnet. There is a simple rule for determining which will be the north pole of such a coil. If you look at one end of the coil, and if the direction of flow of current i.e. from the positive terminal as indicated is the same as that in which

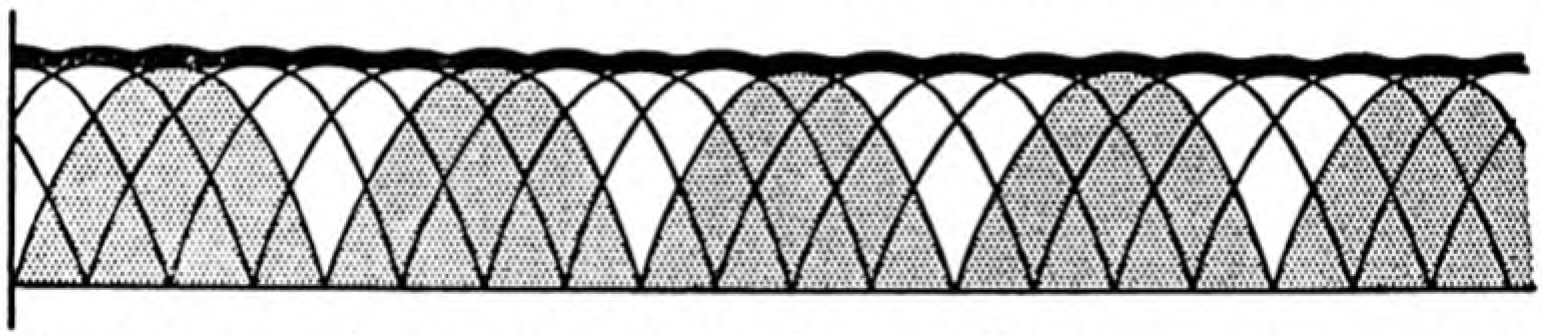


Fig. II, 5.—The output voltage from a direct current generator with a number of coils

the hands of a clock normally turn, then the end you are looking at is the south pole.

The reason why electromagnets are used for providing the magnetic fields in generators is that a much more powerful field is required than could possibly be provided by a permanent magnet. In addition, the control of the strength of the field, which can easily be carried out by controlling the current in the field coils, is an important factor in operating the machine.

Thus, a modern direct current generator will consist of a number of poles, perhaps 10 or even 20, which will be arranged on the inside of a strong steel ring forming the stator, or fixed part. These poles will have insulated copper wire or bar windings on them, so arranged that each alternate coil will produce north and south poles at the inside end (Fig. II, 6).

Running inside the stator will be the rotor, or armature, which will consist of a drum-shaped assembly of thin iron sheets clamped tightly together, and having transverse slots all round the circumference. In these slots will be the coils, and these will consist, again, of insulated wires or (for the larger machines) bars, the ends of which are connected to the bars of the commutator. There are a large number of

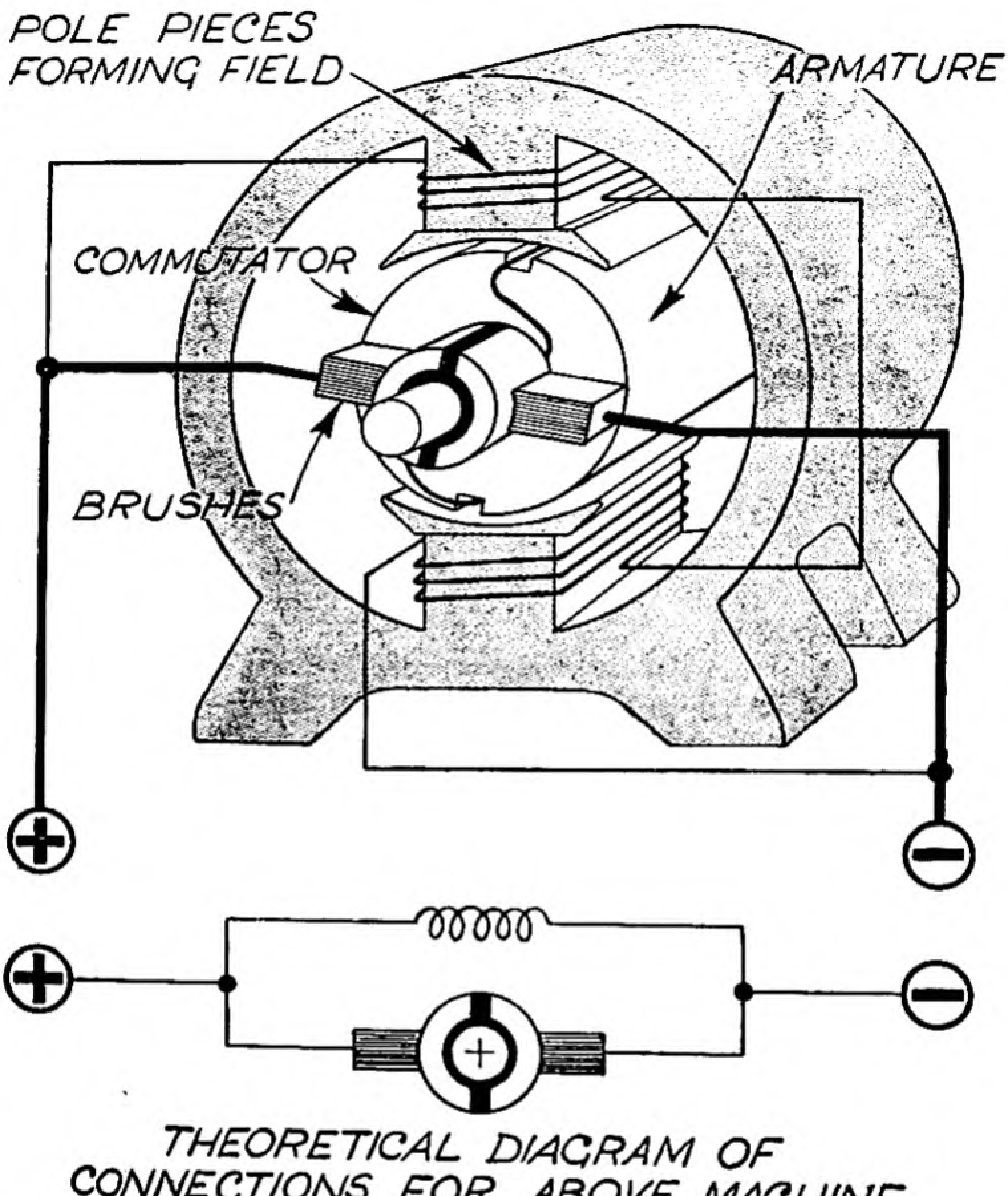


Fig. II, 6.—The elements of a direct current generator

ways in which the windings may be connected to the bars; for example by joining one coil end-on (in series, as it is called) to another, twice the voltage may be obtained, the two outer ends being connected by the appropriate commutator bars. A number of coils may be joined with like ends together, so that they are "in parallel". In this way, the voltage is the same as for a single coil, but the current which may be taken out is greater.

There will generally be one set of brushes for each pair of poles, and these sets may consist of a large number of individual brushes, of carbon, held in brush-holders and connected to the terminals by means

of flexible pig-tails of copper braid, so that the current does not have to travel through the moving contact between the brush and the brush-holder.

Direct current generators are built in all sizes, from the sort used in a laboratory and capable of being held in the palm of one hand, to machines requiring 20,000 horsepower to drive them, and used to supply current to motors for operating large steel rolling mills (Plate 1).

Alternating current generators, or alternators, operate on exactly the same basic principle as the direct current generator, but as there is no need to provide a commutator to switch the reverse half-cycle, a different form of practical construction can be used for the larger sizes. Here, the moving part—the part driven round by an engine—usually carries the field. From the point of view of the basic principle, this makes no difference; the same effect is achieved if the wire stays still and the lines of force move to "cut" it, or if the lines of force stay still and the wire moves.

When high voltages are concerned, it is not very convenient to have to deal with them at points where contact has to be made with a revolving part, as would be the case if an alternator was designed along the elementary lines we have previously discussed. The slip rings, or continuous rings on which the brushes bear, which are connected to the ends of the coils, are not suitable for dealing with voltages above two or three thousand volts. The field is therefore made to revolve, and the high voltage windings, in which the voltages are induced by the field sweeping them as it goes round, are safely tucked away in the stator. This takes the form of an outer steel ring, in which there is an inner ring of iron sheets with slots cut in them all round the inner circumference. In these slots are the windings, which may be connected up to give any desired number of poles and voltages.

An alternator has to have a source of direct current to "excite" the field, whereas the direct current machine provides its own. Therefore a typical alternator will have a small direct current generator on the end of its shaft, so that this exciter, as it is called, turns with the main machine and automatically provides the direct current necessary for the field. This current is led into the field winding, which is situated in slots on the rotor, by means of two slip rings, which have to carry a voltage of only a few hundred volts.

For the smaller alternators, such, for example, as those which might be used to provide an emergency supply to a factory in case of mains failure, the form of construction in which the field is on the stator, as in a direct current generator, is often adopted.

We have now taken a brief glance at the types of machine used to

generate electricity on a commercial scale. A question often asked is—if all that is necessary is to spin round a coil of wire between the poles of a magnet, why is so much power needed? The answer is simple. As the armature of a direct current generator, for example, starts to deliver current to the load, it too becomes an electromagnet, and its polarity is such that the magnetic attraction between it and the poles on the stator makes it want to stay stationary. The greater the current, the greater the attraction, and the stronger the effort needed to pull it round. This is, after all, common sense. You cannot get something for nothing, and if you are to deliver a large output, in electric current (which is a form of energy) from a generator, you must put in an equivalent amount of energy at the other end—the engine end.

The engine which drives a generator is usually referred to as the "prime mover". Almost any form of prime mover may be used, but for each of the various types of electric power generation most commonly employed, certain prime movers have been found to be most suitable.

Starting at the lowest end of the scale, from the power point of view, the generators used to charge the batteries of moving vehicles, such as cars, trucks, trains, boats and aeroplanes, are usually driven from the vehicle engine itself by means of direct coupling, or through a belt drive. For cars and boats and trains, direct current generation is usually employed, the voltage being 6, 12, or 24 volts. A typical car dynamo will deliver 12 volts 24 amps, so delivering 288 watts.

For large trucks and for aeroplanes, generation may be either direct current or alternating current. There is a considerable move towards using an alternating current generator on large vehicles because when the direct current generator becomes very large, its efficiency is so low, and its maintenance presents such a problem that the use o alternating current generation, with subsequent conversion to direct current, by means of a rectifier (described on page 46) is found to be more efficient.

For aircraft, there is a considerable tendency to use alternating current generation at a high frequency—usually 400 cycles per second, 110 volts—since alternators for this frequency are lighter and do not suffer from certain disabilities such as the brush troubles found at high altitudes when direct current is used. Nevertheless, direct current is still employed on many aircraft.

Wind Power

Still in the small power range, the generation of power from the wind is usually carried out by using a direct current generator, similar

to that employed for the motor-car, the generator being mounted on the top of a mast, so that it can revolve to enable the propeller always to face into the wind. The advantage of direct current generation for the small installation is that the current can be stored in a battery of accumulators, and this is not possible with alternating current unless a rectifier is used, which adds to the cost. In the case of larger wind generators, however, alternating current is used exclusively, as will be mentioned later.

In the medium power range, extending from, say, 10 h.p. to 1,000 h.p., petrol engines, diesel engines, gas turbines, water-wheels, reciprocating steam engines, and steam turbines are all used for driving electrical generators.

The Gas Turbine

The gas turbine is the land-based counterpart of the jet engine. A wheel with blades, like a windmill, is enclosed in a casing in which there are corresponding blades through which hot gas, caused by continuous burning of oil fuel, is forced out, so causing the blade-wheel to turn round. These engines are being used to power emergency generating sets and—for example—the Bank of England, in the City of London, has a 750 kW gas turbine set in its basement to take over supply if the ordinary mains fail. In the Middle East, and in America, many gas turbines are at work providing power on the oil-fields, since the turbine will use either the natural gas or the crude oil (Plates 2 and 3).

Internal Combustion Engines

Petrol or paraffin engines are used for small electrical generating plants, often installed in isolated premises, or perhaps as standby plants in hospitals, cinemas, and so on, but the petrol engine is being superseded by the diesel engine for such purposes, mainly on account of the cheaper running cost, as fuel oil is less expensive than petrol. The fire risk is also reduced. Many such plants are self-starting; if a button is pushed, or if an automatic device connected to the ordinary mains is made to operate on mains failure, the engine is run up at once and supplies power instantly. A battery is often used for starting purposes, and to provide energy when the engine is shut down. The smallest plants may be made to start up directly the first load switch is closed, and they will run until the last one is turned off. These plants are costly to run, but the cost of obtaining electrical energy

may not be the deciding factor when considering situations where its amenity value is high, or where a supply of electrical energy is vital, as for isolated weather reporting stations where power is needed for the radio, and for amenity purposes.

Large diesel engines, up to about 2,000 h.p., are used for power generation, but generally the choice of such a type of prime mover has not been dictated by technical considerations but by lack of facilities for steam- or water-power equipment. These large diesels are efficient, but the limiting speed and size of the very large reciprocating parts, and the considerable amount of maintenance needed, mean that they are used only in a very small proportion of the world's power stations (Plate 4).

In the larger sets in this medium power range, the gas turbine is becoming a formidable competitor to the diesel engine, on account of its greater efficiency, its ease in starting, the fact that it will burn very cheap fuel, and its simplicity of construction.

Water Power

Water-wheels are among the oldest form of prime movers for any sort of purpose; and they have been used for electrical power generation for as long as generators have been made. Mills, in which corn is ground, still use the undershot or overshot wheel, in which two large-diameter wooden wheels, with a number of slats running between them, revolve under the influence of the relatively slow-running stream of water brought to them from the river. A generator is sometimes coupled to the shaft by a belt, to provide for the small motors and lights in the mill.

For the larger water-turbine installations, three main forms of turbine are used, according to the "head" of water—the drop available from the water level at the reservoir to the turbine itself. For very high heads—over 750 feet, for example—the impulse turbine, or Pelton wheel, is used. The water is confined by piping into one or more nozzles, which give out jets of water, which impinge on wheels having specially shaped buckets around their rims. The wheel and the nozzle are both enclosed in a casing, so that no water is lost by being sprayed away from the wheel (Fig. II, 7).

In the case of medium heads, say from 750 feet down to 20 or 30 feet, the Francis, or reaction turbine is used. This takes the form of a snail-like casing to which the water is brought by piping, and inside it is a ring of gates which can be opened and shut to control the flow and which direct the water on to vanes on the runner. This runner is of

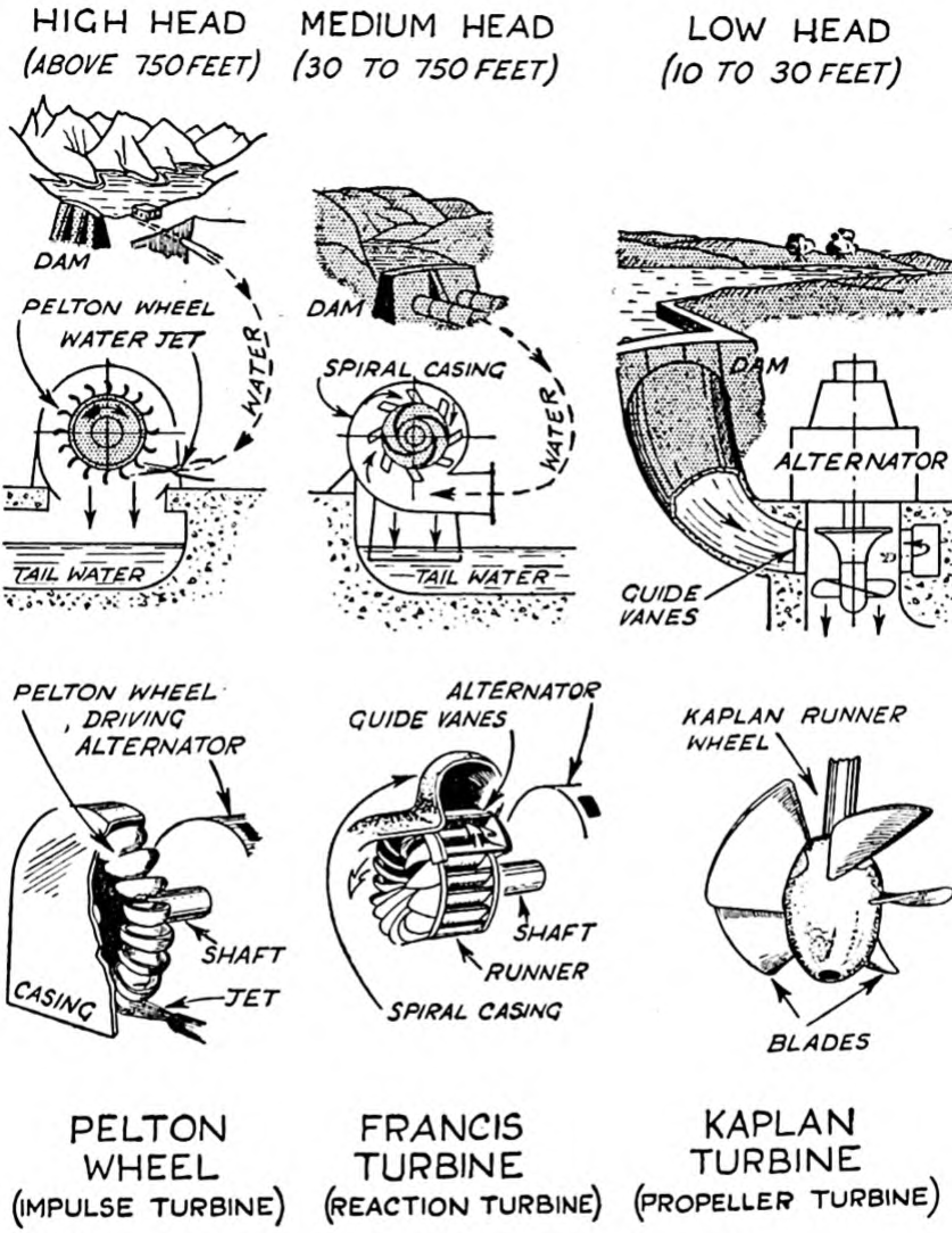


Fig. II, 7.—The various types of water turbine

steel and has top and bottom rings, between which the curved vanes are situated. The water then runs away down the draught tube, from the centre of the runner (Plates 5 and 6).

Finally, for the lowest heads, down to about 10 feet or even less, there is the Kaplan turbine, with or without movable blades. The

spiral casing—the snail-shaped pipe into which the water is taken—is much the same shape as for the Francis turbine, but the runner is formed like a ship's propeller. To enable some installations to be suitable for operations on varying heads of water, the propeller blades may be made to vary in pitch (Plate 7).

All three types of water turbine may be made in the horizontal or vertical designs: that is to say, with the shaft—which directly couples the turbine and the generator—running horizontally, or vertically with the generator or alternator above the turbine. The vertical design is the most usual form for large installations.

The type of alternator used for water turbines is rather different from that employed for other prime movers, although the principle is, of course, the same. The difference hinges on the speed of the turbine, which is much slower than that associated with diesel engines or steam turbines, usually being of the order of 100 to 300 revolutions per minute (r.p.m.).

An alternating current generator has to maintain the same frequency as that of the supply, which, as mentioned earlier, is 50 cycles per second in Great Britain and Europe generally, and 60 cycles per second in America. As we have seen from the elementary generator we first considered, one revolution of a coil in a simple two-pole machine will produce one complete alternation of voltage. If the coil revolves, say, 3,000 times a minute, it will produce 3,000 alternations per minute, or 50 per second. (This is usually described as 50 c/s.) If there were *four* poles on the machine, each revolution would produce two cycles; if there were eight poles, there would be four cycles per revolution. This relationship can easily be expressed by the simple formula:

Frequency (in cycles per second) = Revolutions per second × Number of *pairs* of poles.

From this, we can see that if the speed is low, the number of poles, to produce a given frequency, must be high. And so the water-turbine generators, having to run at a slow speed (unlike the 1,500 revolutions per minute, or even 3,000 r.p.m., of the steam turbine) have to have twenty or thirty poles. These are arranged as projecting or "salient" poles, round the circumference of the magnet wheel or rotor; and this form of construction means that a water-turbine alternator is very much larger than a steam turbine-driven alternator for the same output.

Water turbine-driven alternators are made in very large sizes, exceeding 120,000 kilowatts (kW) in a single unit. About half the

world's electric power comes from the energy in falling water, most of the remainder being generated by steam turbine-driven generators.

Steam Turbines

The largest generators in the world are those driven by steam turbines, and they are made in units as large as 250,000 kW. To achieve the highest possible efficiencies the steam temperatures and pressures are raised to very high figures; steam temperatures of well over 1,000°F., and pressures of 1,200 pounds to the square inch, are common.

The steam is brought to the high pressure end of the turbine, where the blades are small, as only a small surface is needed when the pressure on every square inch of it is so high. Here, by passing through a series of nozzles on to a corresponding series of blade-wheels, the steam gives up a proportion of its energy. When its pressure has dropped a little, larger blades are needed and the steam then passes to the intermediate pressure section. Again, it gives up more energy in driving the blade-wheels round, and when its pressure has dropped still further it passes to the low pressure turbine where the blades—which were only four or five inches long at the high pressure end—are now as long as two feet six inches. The steam has not yet given up all its energy; as it passes the last blade-wheel, it goes into the condenser, where it is brought into contact with tubes containing cool water, usually taken from a river or from a cooling pond. This has the effect of condensing the steam, which, in collapsing from a gas into water, leaves a vacuum, and this vacuum has the effect of "pulling" the last stage blades round, just as the steam, all through the turbine, has "pushed" the others (Plate 8).

Atomic Power

It is appropriate here to mention the effect which the development of atomic power will have on electricity generation.

Nuclear fission—the splitting up of the nucleus of the atom—means that one element is made to change into another, with the liberation of energy. The old alchemists tried to change lead into gold; but until recent times it was thought that the ultimate "bricks" of which matter is made, the atoms, were immutable. Now, we know that matter and energy are in effect the same thing; and consequently a change in matter, in a particular direction, results in energy being liberated. This energy takes the form of heat. To change it again into

electrical energy means that we have to make use of the same processes as those used in a steam power station. In the ordinary steam power plant the chemical energy in coal is changed into heat energy by combustion; and in the nuclear power plant the heat comes, instead, from the "atomic pile". It is carried away by some fluid which is not affected by radiation from the pile, and then generates steam in a heat exchanger, or boiler. After that stage, the nuclear power plant

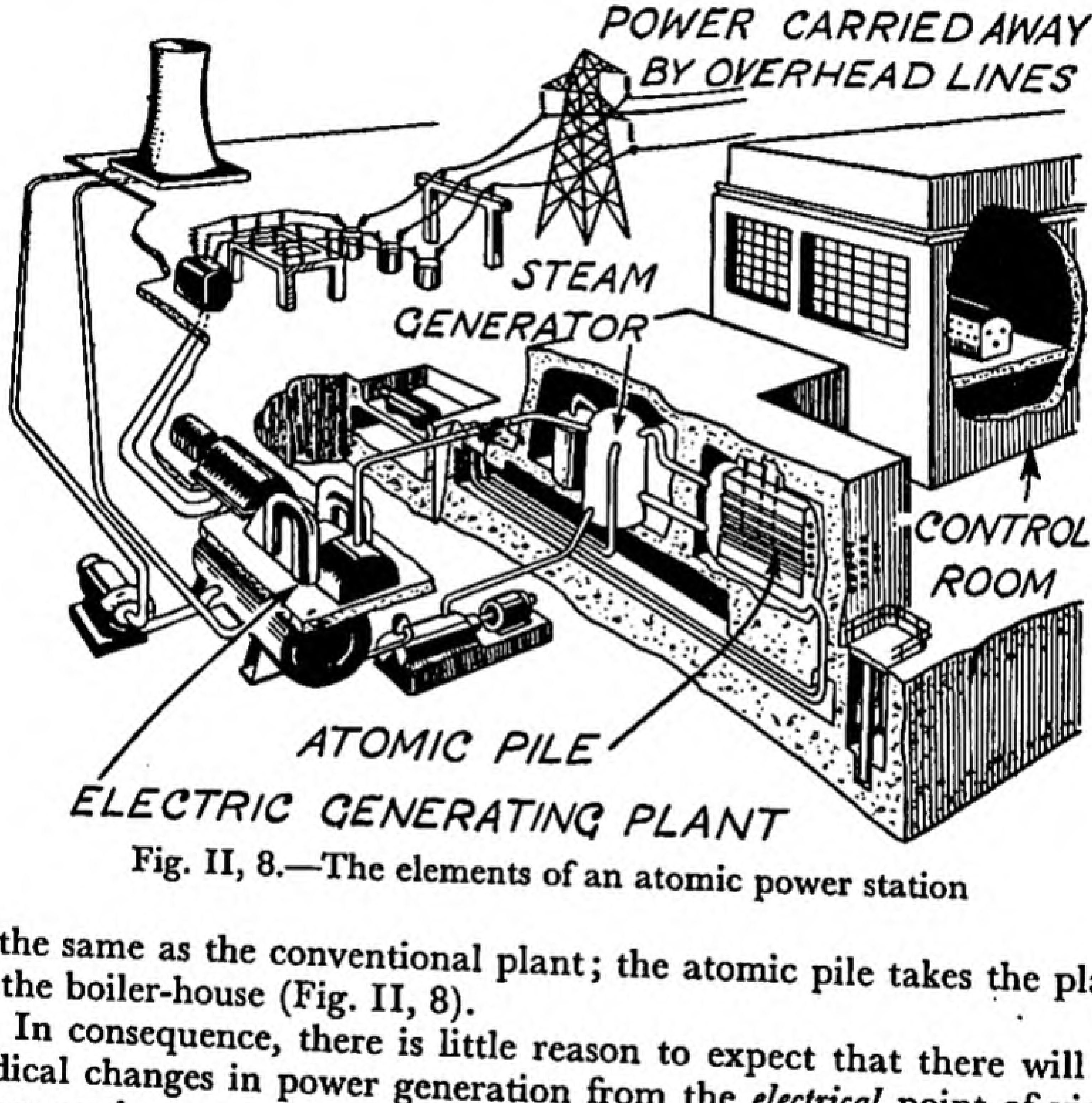


Fig. II, 8.—The elements of an atomic power station

is the same as the conventional plant; the atomic pile takes the place of the boiler-house (Fig. II, 8).

In consequence, there is little reason to expect that there will be radical changes in power generation from the *electrical* point of view, when nuclear power plants become common.

Before leaving power generation, we must touch briefly on sources of energy other than coal, oil, falling water, or the atomic nucleus.

Large-scale Wind Power

There has been a great deal of interest, in the years since the Second World War, on harnessing the wind on a large scale, for

power generation. The problem presents many difficulties, particularly since the wind is variable both in speed and direction. A simple propeller, on a pylon, would run at a speed which constantly varied; but, as we have seen, commercial generation, on a large scale, needs alternating current at a fixed frequency, and this implies, from the formula given previously, a certain fixed speed on the part of the prime mover. A windmill tower has to be high, to catch the wind, but it obviously becomes impossible to instal very large generators, weighing many hundreds of tons, at the top of tall towers.

The largest wind generator yet built was constructed in America during the 1939–45 war, at Grandpa's Knob, Vermont. It could generate a power of 1,250 kW, and it stood on a tower 110 feet high, the two blades sweeping a circle 125 feet in diameter. Control of speed was obtained by feathering the blades, or altering the angle of pitch. Gearing was necessary, in addition, as the windmill ran too slowly for the alternator. As the top of the tower, carrying the equipment, had to revolve, a further complication arose from the need to collect the current, by means of slip rings, from the moving part for transmission through cables to the load on the ground.

The design of a French inventor, the late M. Andreau, developed by a British firm, and first tried out in 1953, seems to have solved most of the problems of wind generator designers. It uses a new mechanical principle (Fig. II, 9).

The two windmill blades are hollow, at the ends are holes which communicate with the hollow axle. This in turn is open to the hollow tubular shaft which supports the windmill. As the blades revolve, air is expelled from them by centrifugal force. As the air flies out, it sucks more air in through the axle and up the hollow tube, from openings near the ground. Just above these openings is situated a turbine-wheel, not unlike that used in a steam turbine, which drives an alternator. As the air rushes up the steel tube, it passes through the turbine-wheel and so causes it to revolve, and to generate power.

The advantage of the Enfield-Andreau wind generator is that the heavy parts—the turbine and the generator—are at ground level; moreover, there is a flexible coupling in the form of a column of moving air, between the actual windmill and the generator, which assists greatly in ironing out speed variations. The blades are also arranged for feathering, to act as the main speed control. A 100 kW wind generator, the first to be used in Great Britain to feed into the Grid, is 100 feet in height, and the swept circle is 80 feet.

The disadvantage of any wind generator is that it cannot generate power when there is no wind and thus it cannot be relied on as the sole

source of power for a community or a factory. Nevertheless, ways are being investigated for storing the energy; for example, the current may be employed in splitting up water into hydrogen and oxygen which can be stored and then, when there is no wind, the gases can be used in a gas engine to generate power. But the use of wind power in connection with a Grid system, such as we have in Great Britain, where all power stations are connected together to all the consumers, means that every unit of electricity generated anywhere, by any means whatever, at any time, can be used to save coal, which is vitally important. Thus, we may expect in the coming years, in spite of the onset of nuclear power, to see considerable developments in wind power generation.

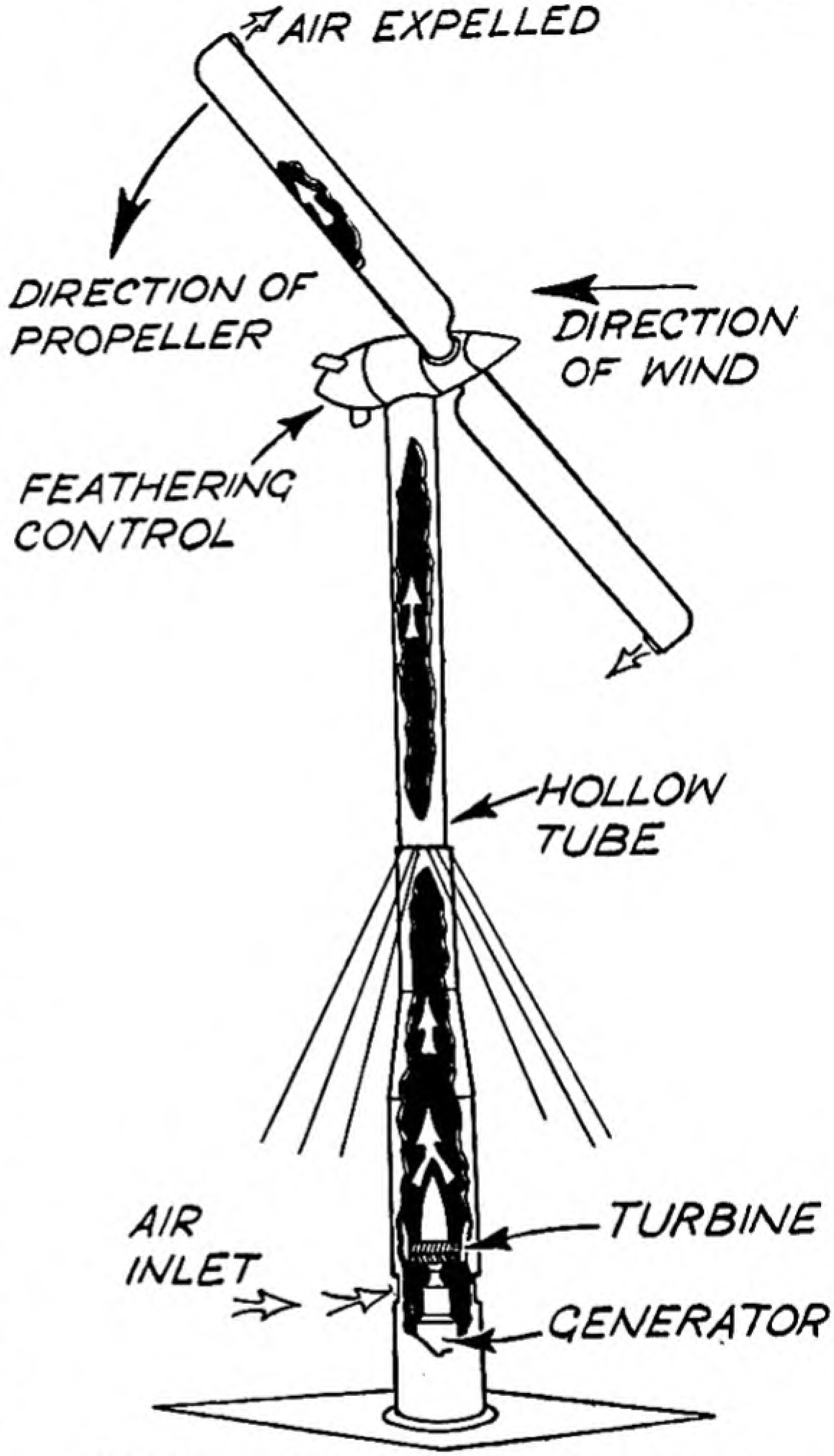


Fig. II, 9.—The principle of the Andreau wind generator

Tidal Power

Next, there is the question of harnessing the tides. The problem here has something in common with the wind; the tidal energy, in one

particular estuary, would only be available for a few hours before and after high tide. The tidal water would be trapped inside a barrage built across a river as the tide rises, and then, when the water outside the barrage had fallen as the tide receded, water would flow out through sluice gates and so generate power. The capital cost would be high, since enormous civil engineering works would have to be built; but although tidal power could not provide a reliable power source for twenty-four hours a day, the very large amounts of energy which could be generated would save a substantial amount of coal each year.

Solar Power

The energy which pours down on the earth's surface each second from the sun has long formed the subject of a fascinating study for engineers who wish to try and catch some of it and turn it into electrical or thermal energy of a kind which can be directed into useful channels. A number of experiments with mirrors, to direct the sun's rays on to boilers, have taken place during the last fifty years, mainly on the Mediterranean coast. Unfortunately, the conclusion has had to be reached, after careful examination during the post-war years of every relevant factor, that the possibilities of generating useful amounts of power in this way are very remote. The mirror surface necessary for even 10 kW of power runs into hundreds of square feet, and the whole of this surface would have to be turned round with the sun.

There are, however, methods by which the sun's energy may be used indirectly to generate power. The French Government is sponsoring some interesting and long-term experiments on the Ivory Coast, at Abidjan, whereby the difference in temperature between the water at the surface of the sea and that of the deep water is utilized in a form of a steam turbine. It is well known that water will boil at lower temperatures at the tops of high mountains; this is because of the reduced atmospheric pressure, which (to over-simplify slightly) allows the vapour to leave the liquid more easily than when the pressure is at the normal figure of about 14 lb. per square inch. If the pressure in a water vessel is reduced very considerably, it will boil even at ordinary room temperatures.

This fact is made use of in the Abidjan experiments. Warm water from the hot surface of the tropical sea is pumped into a vessel to which a vacuum pump is connected. As the vacuum increases, the water "boils", and the vapour is led through a turbine-wheel to a condenser, where it is cooled by cold water pumped up from the depths of the sea. The condensing operation causes the vapour to

change back into water, and in doing so creates a suction effect which drives a turbine-wheel and consequently rotates the generator to which it is coupled. A temperature difference of about 100°F. is available for most of the year, and it is calculated that the capital costs and the cost of the energy lost in the pumps and in creating the vacuum will not render the scheme uneconomic.

A second method whereby the sun's rays may be harnessed is that of photosynthesis. If plants are grown in tropical regions, where there is almost continuous sun, very large crops of suitable plants can be harvested twice or even three times a year. These plants may be suitable for making alcohol, which is a power-producing spirit, and may be used in internal combustion engines, including gas turbines. The sun's rays, acting in conjunction with the chlorophyll in the plant structure, are thus directed into the paths required by the electrical engineer.

Heat in the Earth

A number of attempts have been made to utilize the energy existing in the hot mass at the centre of the earth. Sir Charles Parsons estimated that this is equivalent to 30,000,000 times the amount of coal still in the earth. The temperature rises by 10°F. each hundred feet in depth and it has been thought possible to send down water in pipes, into very deep bore holes, perhaps twelve miles below the surface, where temperatures are so high that water would at once be turned into steam. Again, the capital costs would be very high, and this method of generating power is not likely to be tried out, at any rate on a large scale, in the near future. However, at Lardarello, in Italy, and in New Zealand, there have been determined and successful attempts to use the energy from the heat in the earth, which manifests itself in the form of hot springs and steam wells. About one-eighth of the whole of Italy's power is generated by means of special steam boilers adapted to use natural steam for providing energy for steam turbine-driven alternators.

Electro-Chemical Methods, and the Fuel Cell

In another field, we must mention electro-chemical methods of generating electricity. In Chapter VI (p. 62) we shall examine the ordinary battery, which provides the power for the pocket torch and for the portable radio set. This battery, known as the Leclanché cell, uses poles of zinc and carbon, in an acid solution, to generate an electromotive force. When current is drawn, the zinc is consumed. The type of refined zinc required for primary cells, as they are called, is

expensive and it would not be conceivable to generate commercial power in this way. For many years, scientists have been trying to evolve a form of cell in which the basic form of fuel—coal—can be used to generate power *directly*—that is, without the intermediary of a boiler, a steam cycle, and an electromagnetic generator. As the efficiency of even the best power station does not exceed 36 per cent, and cannot, owing to the limitations of the steam cycle, ever reach more than about 45 per cent, there is obviously a very potent challenge in designing a fuel cell, as the "coal battery" is described, which would have a higher efficiency and use less irreplaceable coal to generate a unit of electricity. British, American and Russian scientists have worked at this problem with greater intensity in recent times, and it appears that there is a possible solution which may be the basis of a practicable fuel cell.

The method used is to convert the coal, by a form of slow combustion, into water gas, which is a mixture of carbon monoxide and hydrogen. This gas is introduced into the pores in one of the two electrodes of which the cell is made up, the other electrode using the oxygen in the air, again forced into the pores. Thus hydrogen and oxygen are the real substances used up, but the carbon is also consumed in preparing the hydrogen, which comes from water and is, therefore—like the oxygen from the air—"free". The fuel cell, when it becomes a practicable proposition, will generate power in the form of low voltage direct current (about one volt per cell unit). Thus, to couple it to our existing alternating current systems, special apparatus will be neccessary. However, one of its first uses may well be in connection with the large amounts of low voltage direct current power needed for electro-chemical processes.

There is yet another method of generating electricity into which research is being pursued with vigour, even though it may be many years before large-scale power can be produced. As stated on page 15 if bars of two dissimilar metals are so arranged that a chain is made up, with metal A, metal B, metal A, and so on linked in series, and if every alternate junction is heated (the other being kept cool) an electromotive force will be set up across the ends of the chain. It will be of a very small order, less than a thousandth of a volt (a millivolt) per degree of heat difference between each hot and cold junction; but nevertheless with sufficient junctions in series—several thousands—a useful voltage can be obtained. In many industries there is inevitably a very considerable amount of waste heat, for example, in blast furnaces. If thermo-electric generators can be developed so that they are practicable in large sizes, they may well serve to make a useful contribution to fuel saving by utilizing heat which up to now has been wasted.

CHAPTER III

FORMS OF UTILIZATION

An electromotive force, produced by a generator, which is ready to cause current to flow if applied to an external circuit, may be either (*a*) steady in value, and always in the same direction; (*b*) always in the same direction but varying in value according to some sequence of events, such as the turning of a coil in a magnetic field; or (*c*) alternating in direction and value according to either a "sine wave", as in the elementary generator discussed in the last chapter, or to some other sequence, which may be repeated at a frequency of up to millions of cycles a second.

Turning back to Faraday's original discoveries, it will be recalled that when a coil of wire is "cut" by a magnetic force a voltage is induced in it. Neither the coil nor the flux need be physically moved; if the flux varies, the effect is the same. Imagine now a ring of iron having at one side a coil with, say, 200 turns of wire (Fig. III, 1). Let us imagine that on the other side of the ring there is a coil with 2,000 turns. Now suppose that the first coil—the "primary" coil—is connected directly to the slip rings of a simple elementary alternator as described in the previous chapter, and let us imagine that this alternator produces a voltage of 100 volts. An alternating current will flow in the coil, in accordance with the rise and fall of voltage produced by the rotation of the coil in the alternator between the poles of the magnet. This will create a magnetic flux in the iron ring—that is to say it will make it into an electromagnet with the lines of force alternately going one way and then the other, as the alternating current changes in direction. The second coil, which has more turns, embraces this magnetic flux in the iron.

Imagine for a moment the start of a cycle of the alternating current wave. At the zero point there will be no magnetism in the ring. As the

current builds up in the primary coil, in a positive direction, lines of force will be set up in the iron ring which will effectively cut all the turns of the second coil. Each of these turns will have induced in it a certain electromotive force; and by "adding the turns together", so to speak, the electromotive forces are added together. Thus a voltage will appear at the end terminals of the secondary coil. The magnetic flux circulating in the iron ring is of course the same for both coils and thus the voltage per turn is the same in both. If one coil is assumed to have ten times the number of turns as the other coil, then it is obvious that the voltage across the terminals of that coil will be ten times that across the voltage of the other.

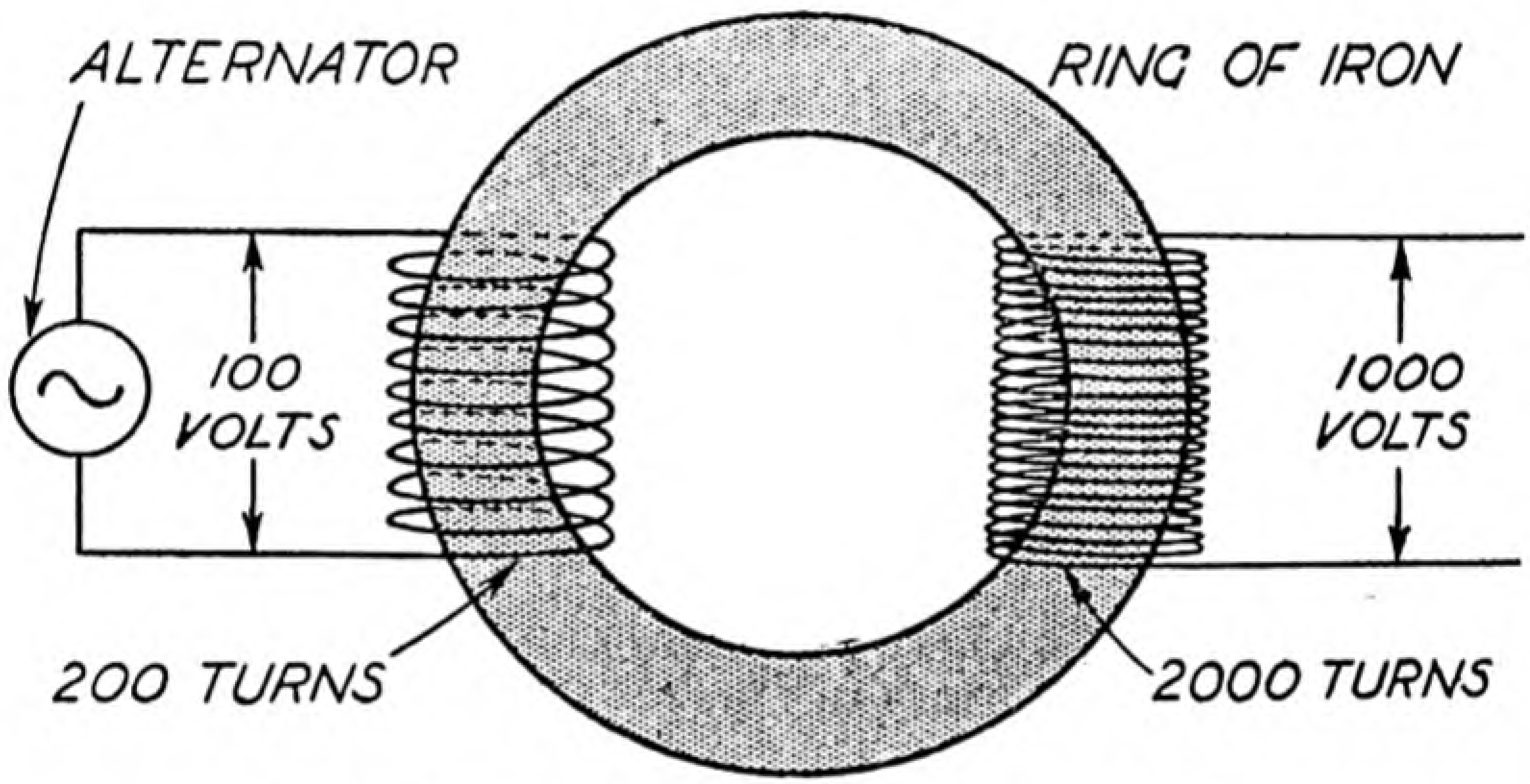


Fig. III, 1.—The principle of the transformer

This is the basic principle of the transformer—perhaps the most important factor of all in making electrical energy widely available, no matter how far the distance from the power station (Plates 9 and 10).

(It should be mentioned that the above description has been a little over-simplified in the interests of clarity; in point of fact there is a lag in the production of the magnetic flux after the voltage from the alternator has reached the primary coil. This aspect will be dealt with later.)

In the early days of electricity supply, the engineers always tried to use direct current because they could use storage batteries and so need not run the generating plant all night, when the load was very light. But they soon ran into difficulties. When the mains began to

extend over several miles from the power station, the power lost in the cables themselves began to assume serious proportions. As the voltage was limited by the pressure which could safely be handled by the commutators of the dynamos, there was no possibility of using a higher voltage than about 5,000 volts, and this voltage was in any case too great to be applied directly to the various consuming devices. A higher voltage would, however, have had the effect of reducing the current needed, and so reducing the losses. Thus there seemed to be a limitation in the distance over which electrical energy could be transmitted.

Among the main problems still encountered in transmitting electrical energy over long distances is that of the loss in the conductors used to carry the current. These conductors themselves possess resistance, and when they become very long the resistance of the conductors may be as great or greater than the resistance of the load. Thus a very high proportion of the energy will, in simple terms, be "absorbed" by the transmission cables, and will not reach the point at which it is to be usefully employed.

The loss in transmission cables is largely a matter of the value of the current flowing; if large currents are to be carried (for example currents of the order of 10,000 amperes) either very large conductors indeed must be used, or else the loss will be very great. It is not practicable to use copper conductors (particularly for overhead lines), which are as thick, say, as a man's wrist. But since the power transmitted is represented by watts, which are measured as the product of volts times amperes, the same power can be transmitted on a given circuit either by a high voltage and a low current, or a low voltage and a high current. With direct current generation, in the early days, there was no way of changing the voltage up and down as required. Consequently the voltage at the consumer's terminals had to be of the same order as the voltage of the generator.

The Transformer and its Work

All this was altered by the advent of the transformer, which has the effect of changing the voltage up or down as required; thus, if it is convenient to generate at a relatively low voltage and then to transmit at a higher voltage the transformer enables this extremely useful operation to be carried out.

In actual fact generation in modern power stations is usually carried out at about 11,000 to 15,000 volts, alternating current. To transmit this power over long distances, the voltage may be raised up to a figure as high as 400,000 volts. In this case, with the high voltage

the current is low and consequently reasonably small conductors can be used. But when the energy arrives at the receiving end of the transmission line, obviously it must be reduced in voltage to a figure at which it can easily be handled for the consumer's own purposes. Here again the transformer comes into play and the usual arrangement would be to have a transformer to reduce the transmission line pressure to about 110,000 volts, where it would be sent into a minor network of transmission lines, carrying the energy to the main load centres. At these centres, further transformers would be used to reduce the voltage still further, this time perhaps to 33,000 volts, where once again it would feed still smaller networks. The final transformation would be from 33,000 volts to 415 volts, at which voltage the energy would be brought into the consumer's premises. As we shall see, the domestic supply voltage of 240 volts is derived from the 415-volt three-phase system.

Once the energy has been brought to the point where it is to be utilized it may undergo a further conversion into direct current. This is because a very large amount of the world's electrical energy is used on electro-chemical processes, such as the melting down of aluminium ores, the production of fertilizers and so on which require direct current. Not only is it used for the purposes mentioned above, but it is also employed on a large number of electric railway systems, and there are other large users of energy, such as the Post Office for its huge telephone exchange batteries, where again direct current is essential. The large rolling mills where the vast quantities of steel needed every day are produced employ direct current motors of sizes which may be as big as 20,000 horsepower, to drive the rolls between which the hot ingots are squeezed into shape. In another field of utilization altogether, every radio receiver and transmitter needs high voltage direct current to provide the supply to the anodes of its valves.

In addition to these utilization aspects of direct current, there is also another field in which it may be employed. Although the transformer enables the very high voltages needed for long-distance high power transmission schemes to be provided quite easily, there is a considerable advantage to be gained from the use of direct current at voltages of about 500,000 volts for certain transmission schemes, where the flexibility of alternating current is not required. This is particularly the case in projects where a submarine cable is involved, and the world's first high voltage direct current power transmission scheme went into service in 1954, between the mainland of Sweden and the island of Gotland, involving a submarine cable 62½ miles in length. This cable needs only a single conductor, the return current flowing back through the sea.

A.C. and D.C. Uses

To sum up the alternating current and direct current aspects of the transmission and utilization of electric power, first it may be said that all large-scale generation is carried out on the alternating current system; transmission and distribution to consumers are carried out also on the alternating current system (because of its voltage flexibility) although certain very large long-distance power transmission schemes are likely to be carried out with high voltage direct current; and utilization is carried out either with alternating current (for normal domestic and smaller industrial uses), or direct current for electro-chemical work, for applications where valves are used, such as radio, and for large-scale motive power such as railway traction and rolling mills (Fig. III, 2).

To change from alternating current to direct current (and also from direct current to alternating current) some kind of conversion equipment is needed. Two forms are employed: the first is the rotary type and the second is the rectifier.

Conversion and Rectification

The rotary type of conversion equipment simply employs a motor driven from, say, the alternating current system, and driving a generator giving a direct current output. If the reverse direction of conversion is needed, a direct current motor would be employed to drive an alternator. The "rotary converter" is a combined motor and generator, in one frame.

This type of equipment was widely used in the past and still finds application where very large powers are needed. The huge motors, operating on direct current, used for driving rolling mills derive their power supplies from special generators, one for each motor, driven by alternating current motors supplied at high voltage from the supply system. The disadvantage of the rotary type of converter is that its efficiency is relatively low, and its first cost is also high. If small amounts of converted energy are needed it becomes bulky and inefficient. There is, moreover, a limitation of voltage, so that rotary types of converting equipment cannot be used for the very high direct current voltages needed for the large valves in radio transmitters, and for high voltage direct current transmission schemes.

The second type of conversion equipment is the rectifier, and rectifiers may be divided again under several headings. The various groups are known as mercury arc rectifiers, semi-conductor rectifiers and contact rectifiers.

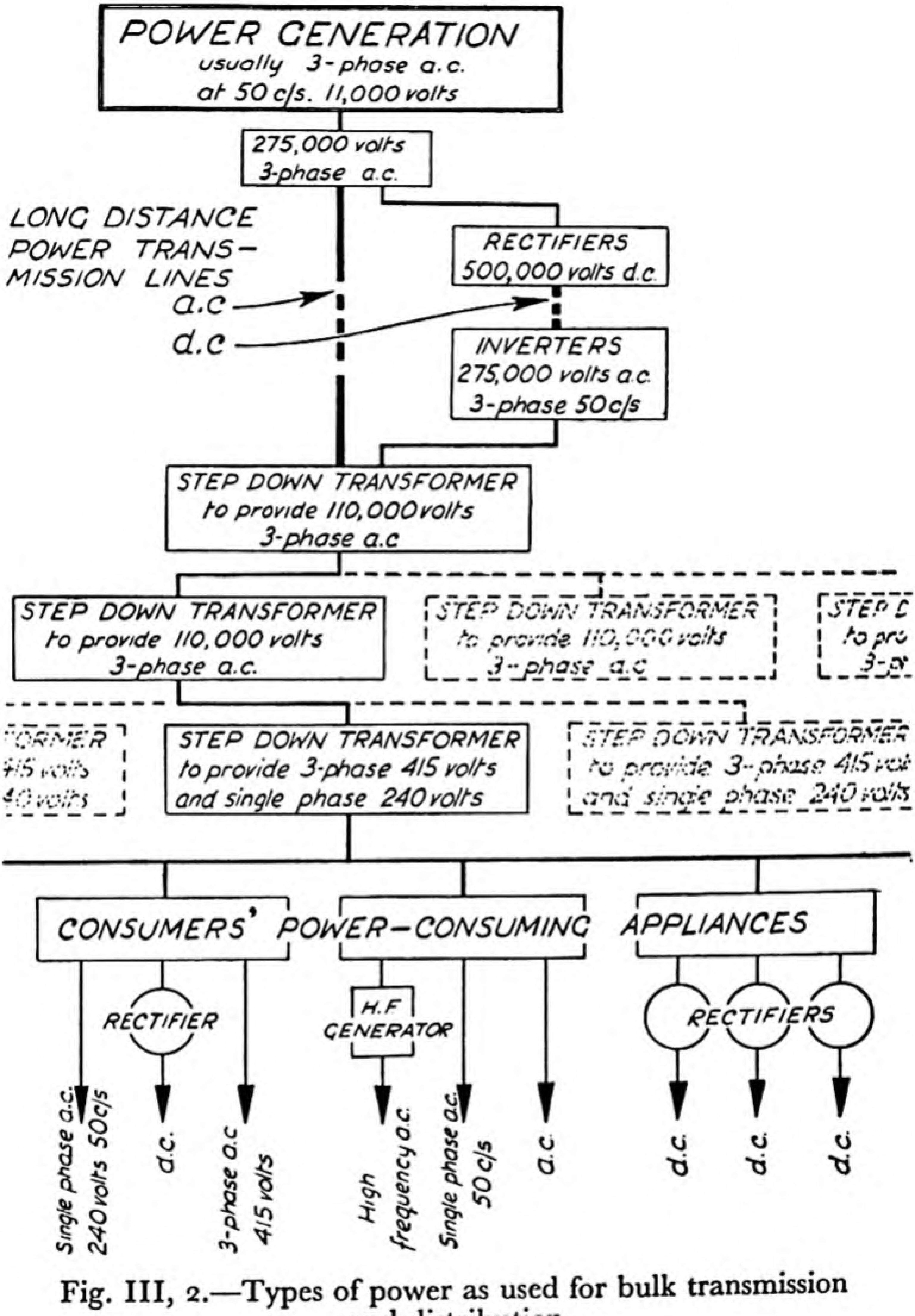


Fig. III, 2.—Types of power as used for bulk transmission and distribution

Perhaps the most widely used is the mercury arc rectifier. In this device a glass vessel (or in the very large sizes, a steel tank) is exhausted of air and a small quantity of mercury is introduced. At the top of the bulb, as the vessel is called, there is a plate of metal which is connected through an insulator to the outside of the tank, and to which

a high voltage direct current potential is applied (Fig. III, 3). If an arc is struck inside the bulb, by means of a special igniter electrode, some of the mercury will be vaporized and will form a conducting path from the mercury to the anode. As long as the positive potential is maintained on the anode—the plate at the top—with respect to the cathode (the mercury pool), current can only flow from the cathode to the anode, and not in the reverse direction.

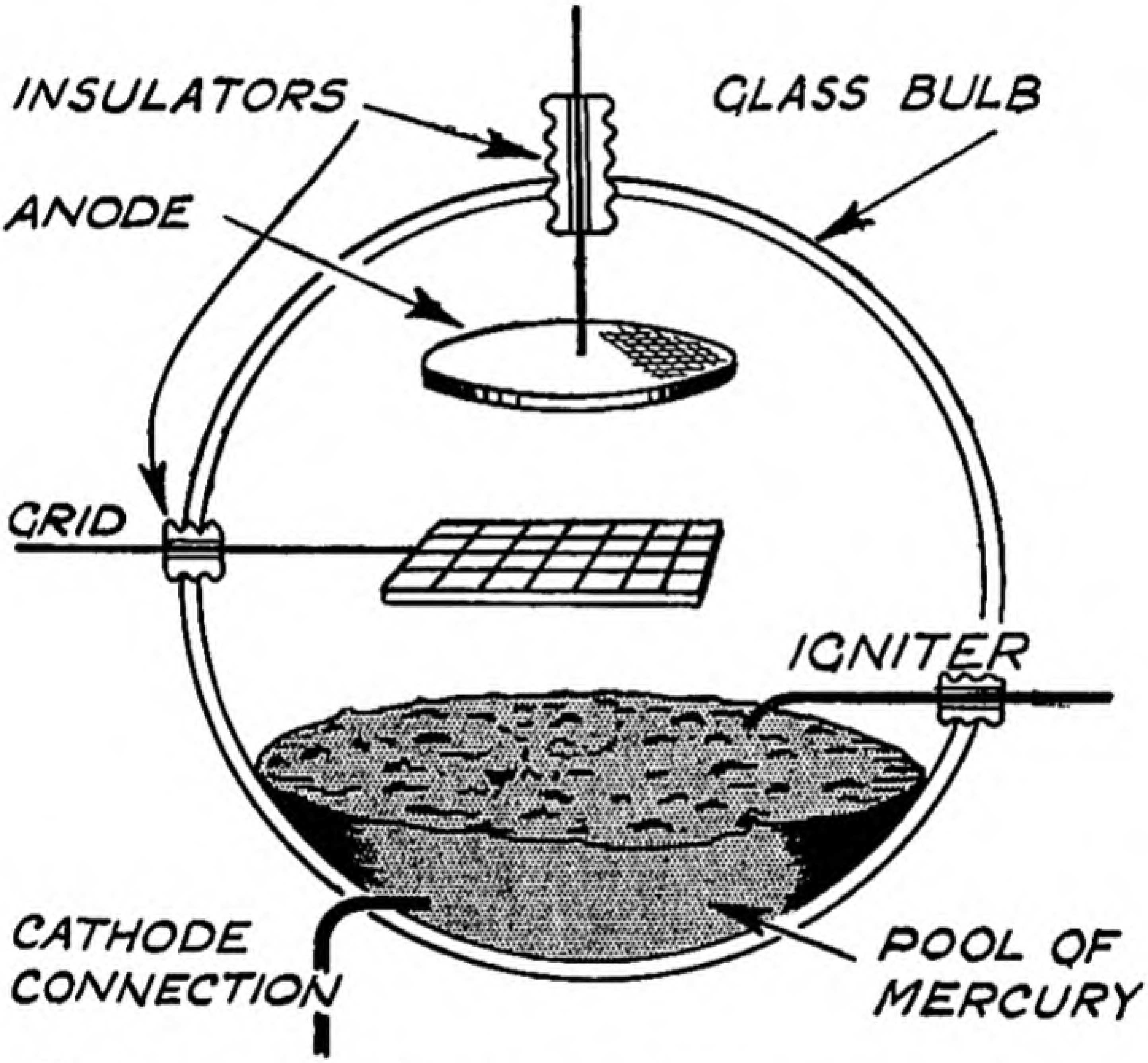


Fig. III, 3.—Simplified diagram of the mercury arc rectifier

If a device of this nature is suitably connected in an alternating current circuit, only the positive half-waves of current will be able to get through it. Thus, a current which is always in the same direction, even if it is pulsating, will flow in the circuit on the other side of the rectifier. By connecting several rectifiers in various circuit combinations, a completely "smooth".direct current output can be obtained—as smooth as if it came from a battery, where there are no variations at all.

The rectifier valve in an ordinary radio or television set operates on

the same principle as the mercury arc rectifier, but mercury vapour is not used. A special type of cathode is used in radio valves, in which a small heating filament, situated beneath a plate coated with special metal, causes an emission of electrons.

The mercury arc rectifier can be built for very large currents and voltages. Rectifiers delivering 15,000 or 20,000 volts are used in broadcasting stations, and rectifiers delivering several thousands of amperes at voltages of perhaps 500 or 600 are used in factories where large amounts of direct current power are required (Plate 11).

A further refinement in the mercury arc rectifier is to introduce between the anode and the cathode a mesh, or grid, of metal connected to the outside of the bulb through an insulator, to which a voltage can be applied. The grid acts as a sort of trap, which will only allow current to flow when it is open, until the next zero point in the a.c. wave. If at this point a new grid impulse is not applied the current flow cannot be resumed. In this way control of the heavy current through the rectifier may be achieved, and this facility is of very great assistance in enabling very small currents to control very large ones.

The grid control arrangement also has another application. If we imagine a rectifier connected in series with a source of direct current, we can vary the current flow through the circuit in any way we like by applying suitable voltages to the grid. If we choose to vary the current flowing in the circuit so that the variations have the same frequency as an ordinary alternating current wave, and if we then put in this circuit the primary coil of a transformer, we have the same effect in the transformer as if an alternating current had been used. Another coil wound on the transformer core will "cut" a varying flux which is exactly the same as that created by an alternating current applied to the primary coil, and the result will be alternating current, at any required voltage, in the secondary of the transformer. In this way, the rectifier is being made to work as an "inverter", and this is the type of device used at the receiving end of a high voltage direct current transmission scheme.

High-frequency Generation—Electronics

Before concluding this brief survey of the methods in which electricity is generated and utilized, a mention must be made of high-frequency power. For commercial use, alternating current at 50 cycles per second is normally used. There are, however, a number of applications of electrical energy for which alternating current at millions of cycles per second is needed. Among these, the principal group is that concerned

with radio, television and radar. There is also another group concerned with electrical heating of certain materials.

For high-frequency generation, as we call the use of electrical energy at frequencies considerably above the normal 50 cycles, the valve is practically the only type of equipment now employed. Alternators may be built for frequencies of up to about 50,000 cycles per second, but they have certain disadvantages even at that frequency; and for the much higher frequencies, running into thousands or even thousands of millions of cycles per second, the use of rotating machinery becomes impossible. Thus the valve, with its very convenient control system by means of the grid situated between the anode and cathode, forms the ideal method of generating high-frequency power.

To make a valve of the ordinary "triode" type, as used in radio sets, into a generator of high-frequency oscillations, it is necessary to feed it with a direct current potential on the anode, and to provide suitable circuits coupling together the anode circuit and the grid circuit. The best analogy to explain the operation of a valve as a generator of high-frequency current is to consider the balance-wheel of a watch. This swings a certain amount in one direction, and then receives a little "kick" of energy from the mainspring making it swing back for an equal amount in the other direction. The hair-spring then returns it, and it gets a further kick from the mainspring, and so on. In other words, it oscillates. The oscillating action of a valve is carried out according to the same general principle. A special circuit is connected to the grid and to the anode circuit so that when a very small pulse of voltage is applied to the grid, it momentarily causes the anode current to increase or decrease. The connection between the anode circuit and the grid means that as the anode current increases voltage is fed back to the special "tuning" circuit coupled to the grid and causes the grid voltage to increase or decrease, in the opposite direction to that taken by the anode current. This has the effect of altering the anode current again to the same degree, but in the opposite direction, and so the whole cycle proceeds once more. The tuning circuit coupled to the grid sets the speed at which this oscillation takes place, and so the valve can be made to produce, in its anode circuit, an oscillating current of any required frequency, even up to thousands of millions of cycles per second.

CHAPTER IV

EFFECTS OF THE ELECTRIC CURRENT

THE heating effect of the electric current is of the greatest possible use to the consumer of electrical energy. It is evidenced every time an electric lamp (of the ordinary filament type) is switched on; every time an electric radiator is used; and in a fashion which is not so obvious, it helps to protect all our electrical systems by forming the basis of operation of the invaluable fuse. A fuse is nothing more, in essence, than a wire which is so far heated by the electric current that it melts and breaks the circuit at a point where this can be done safely.

HEATING

What gives rise to the heat effect? We have seen in Chapter I that the flow of an electric current through a conductor is caused by the application of force at one end, thus causing an upsetting of the atomic or molecular equilibrium, and creating a flow of electrons. If the material of which the conductor is composed has a relatively high value of resistance, we have suggested that the movement of the electrons within the conductor is rather like that of moving water through a pipe filled with some obstructive material, such for example as small pebbles. To pursue that analogy a little further, it will be realized that if energy is in fact expended in forcing water through a pebble-filled pipe, some of that energy will be needed to overcome the friction of the pebbles; and as they rub against each other, heat will be generated.

This pebble-filled pipe analogy must not be taken too far or too literally when considering the passage of an electric current through a conductor possessing relatively high resistance; nevertheless, the basic principle is the same, and heat will be generated.

If the conductor through which the current is passing is of the type we call loosely "a good conductor" (such as copper, aluminium and

silver) then the resistance being small not much heat will be generated by the passage of a particular value of current, which is within the normal capacity of the section of conductor being considered. Even so, some heat *will* be generated, and if the current is increased, the heating effect will also be increased. If, however, the current is flowing in a conductor having a higher resistance (for a particular size of wire) then the same current will create greater heat. From a consideration of Ohm's Law, we see that to force the same current through two different conductors, the resistance of one being twice that of the other, then obviously the voltage will have to be doubled. This, in any case, follows from the general law that "you cannot get something for nothing": heat is a form of energy and if electrical energy is to be transformed into heat energy, then just as much energy must be put in, in the form of electric current, as is taken out, in the form of heat.

The electric radiator usually consists of a spiral of wire of a type which has been specially developed so that it will attain just about the right temperature—a bright, glowing red—with the passage of the sort of current value which can conveniently be handled in a domestic electrical installation. Thus, for a one-bar radiator, which usually has an electrical loading of 1,000 watts, or 1 kW, the current necessary at a pressure of 240 volts across the ends of the resistance element is 4·17 amperes.

We shall see, in Chapter VIII of this book, something of the practical ways in which the heating effect of electric current is applied to various forms of electrical heating devices.

Lighting

To transform electrical energy into light energy, several methods are possible. Most of them act indirectly in the sense that the electric current is used to generate heat which in turn raises the temperature of some suitable conductor to such a degree that it glows white-hot and thus gives out light. The ordinary filament lamp, used by the thousand million all over the world every year, comprises a conductor made of a special metal which will not melt when heated to a white-hot temperature, enclosed in a glass bulb which is evacuated of air so that the wire cannot oxydize and consequently burn up when it becomes white-hot. About 95 per cent of electrical energy expended in a filament bulb is actually in the form of heat; and in spite of the vacuum which retards the direct transmission of heat from the filament to the glass, the temperature reached by the bulb can easily be ascertained if one

is so rash as to take hold of an electric lamp after it has been alight for a long period.

Another method whereby heat is first generated, with a view to creating light, is by the use of the electric arc. This was the first method ever used to create electric light, when, in the middle of the nineteenth century, experimenters coupled the ends of a battery of cells to two pieces of carbon, which were brought together and then slightly separated, resulting in the creation of a steady arc of immense brilliance. In these days, arc-lamps are still widely used, but on account of the heavy currents required and the fact that an arc cannot easily be left to burn unattended for lengthy periods, the use of this form of illuminant is confined to special applications, such as searchlights, arc-lamps for cinema projectors and studio lighting in connection with cinematograph film making.

A third method by which electrical energy may be used to create light is that which is employed in the well-known fluorescent tube.

Certain powders have the special property that they can glow, and thus emit light, when excited by certain radiations. Light itself is in fact a form of energy, with oscillating waves of energy being carried from the light source to the eye. These oscillating waves are not all of the same frequency. The band of light waves, or the spectrum, as it is called, extends upwards and downwards, in terms of frequency of light waves, from the "white light band", which for this purpose may be regarded as normal daylight, and which we may consider as the centre of that part of the spectrum with which we are dealing.

If a piece of iron is subjected to heat there comes a stage when it glows red. If now we placed that red glowing iron bar in a completely dark room, and watched it as it cooled, obviously there would come a stage when all light emission ceased and we could no longer see it; but even when we could no longer detect its presence by means of the eye, we could still feel that it was hot. Thus, as the bar cooled there would come a stage when perhaps one person with particularly acute eyesight could see it glowing faintly, whereas another person under the same circumstances would see nothing at all. This example has been given to illustrate the gradual transition from visible light, or emission of energy waves, to invisible emission. At this lower end of the spectrum the waves with which we are concerned are the infra red waves—below red light. At the other end of the spectrum (taking white light as our centre), there are other waves which, just like the infra-red, taper off into invisibility. These are known as ultra-violet rays, meaning "beyond violet", since violet is the last visible colour at that end of the spectrum. White light is of course a mixture of a large

number of colours, red being at one end of the mixture range and violet at the other.

Ultra-violet rays are brought into being when a controlled arc takes place inside an exhausted glass tube in which there is a small amount of mercury vapour. If we now took a long glass tube, say, 5 feet in length and about 1½ inches in diameter, and then added an electrode at each end, and—after creating a vacuum in the tube—we then added a very small quantity of mercury vapour, we should arrive at the elements of the ordinary fluorescent lamp. But, by applying a voltage across the electrodes, and (as we shall see later) initiating an arc, we produce only the ultra-violet radiations which are of no use for ordinary seeing purposes. But if we had previously coated the inside of the glass tube with the special powders mentioned above, the ultra-violet radiations would cause these powders to glow, thus giving the effect of the ordinary fluorescent lamp. By varying the powders used, we may vary the colour.

There are other types of lamp in which the same principle is in effect employed, and these are the large discharge lamps used for street lighting and similar purposes. A small capsule of very special glass which will resist heat and will transmit ultra-violet radiation is used to enclose an arc set up between two electrodes passing through the tube, and the resulting radiations are employed to excite fluorescent powders placed on an external enclosing glass, with the result that we have either the yellow sodium type of lighting, or the other green- or blue-coloured lamps, depending on the type of powder used, which are a feature of many main highways.

The final form of conversion of electrical energy into light energy is that relating to the neon and other tubes which are used in the illuminated advertisements seen everywhere. The principle on which these operate is somewhat different to that of the fluorescent lamp, although there are certain similarities. In both cases an exhausted glass tube is employed with electrodes at each end. Between these electrodes a high alternating voltage is applied. In the case of the neon-type tube, however, the gas inside the tube is not mercury vapour, but one of the rare gases, such as neon itself (which gives a red light); helium for ivory white or yellow when special glass is used; nitrogen for buff-coloured light, and so on. The electrical side of these lamps is different from that used for the fluorescent lamp because to create a glow discharge in an exhausted tube in which a small quantity of gas is incorporated, a much higher voltage is needed than in the case of the mercury vapour arc in the ordinary fluorescent lamp. Voltages as high as 7,000 volts are often employed on long neon-type lamps.

Production of Mechanical Energy

We now turn to another of the effects of electric current—its ability to allow us to turn electrical energy into mechanical energy.

If we turn back to the elementary electrical generator, it is not difficult to see that if electrical energy were applied to the generator instead of mechanical energy, the same machine could function as a motor instead of a generator. The "right-hand rule" applies to the generator; an exactly similar "left-hand rule" applies to the motor. If a coil of wire carries an electric current it becomes a magnet, with a north and south pole. If this magnet is in the vicinity of another fixed magnet, the north pole of the electromagnet will be attracted to the south pole of the other magnet. If, as it moves towards the fixed magnet as a result of this power of attraction, there is some arrangement to change the direction of current when the two magnet poles have come together, then the north pole of the electromagnet will become the south pole, and will be attracted to the opposite pole of the permanent magnet, and so will tend to move on again. This is the principle of the direct current motor.

Turning once more to the elementary generator, and applying the left-hand rule, we can ascertain the direction of rotation. The forefinger and second finger of the left hand, together with the thumb, are placed at right angles to each other. The thu*M*b represents *M*otion, the se*C*ond finger represents current, and the *F*orefinger represents *Flux*, or direction of magnetic field, which is from north to south poles of the permanent magnet.

If the left-hand side of the conducting loop be considered, and if the current is flowing towards the commutator end (the flux being from left to right), then the direction of motion of that side of the loop will be upwards, that is to say, in a clockwise direction. As the commutator segments come under the brushes the direction of current will change, and so motion will be continuous (*see* Fig. II, 1).

This serves to illustrate the basic principle of all methods of changing energy into mechanical energy. All direct current motors are, in effect, only elaborations of this simple principle. The larger motors have many poles instead of only two, and the field flux is provided by coils wound on the poles, and not by permanent magnets. The armature or moving part will have many turns of wire, and consequently many commutator bars.

The A.C. Motor

The alternating current motor employs the same basic principle, but the practical application is somewhat different.

To appreciate the problems inherent in designing an alternating current motor, it is first necessary to explain the principle of phase displacement. Once again we go back to our elementary alternator consisting of a single coil of wire being spun between the poles of a permanent magnet. If, instead of one single coil, there are three separate coils, on the same shaft, all being spun within the same field, then three separate alternating voltage waves will be set up, one following the other as the assembly of coils is driven round. Suppose

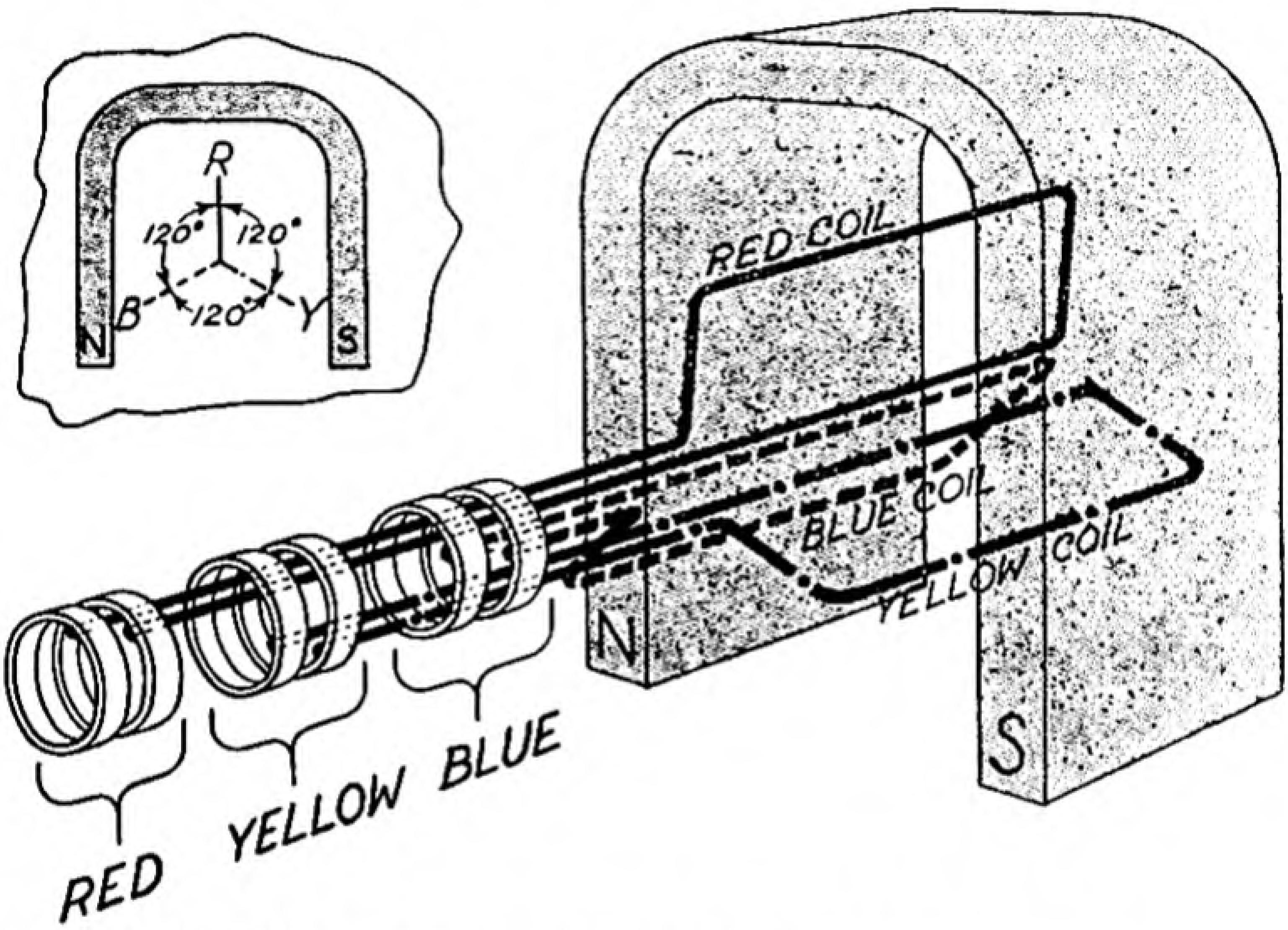


Fig. IV, 1.—The production of three-phase current

now that the three coils are spaced at 120° apart—thus dividing the complete circle of one revolution into equal thirds. Let us call the three coils Red, Yellow and Blue, simply to give them recognizable names (Fig. IV, 1). If we now plot on a graph the voltage wave generated by the red coil as it turns through the complete circle of 360°, we shall produce the well-known "sine" wave curve. But 120° after the red coil has started its cycle, the yellow coil will start its own cycle; and 120° later still, the blue coil will start to produce the third voltage cycle (Fig. IV, 2).

These three voltage cycles, if considered as being produced by three separate unconnected coils, have only this relationship to each other—they happen to be 120° apart, and are rigidly tied to this

relationship because the coils are on the same shaft and cut the same lines of magnetic force. We speak of them as having a phase displacement of 120° with respect to each other. The three coils could have their six ends connected to three pairs of slip rings and the three separate outgoing circuits could supply entirely separate loads. But there would be little advantage in this method of connection. The normal three-phase system has only three or four outgoing wires, and this can be understood if it is realized that the intermeshing of the three voltage waves takes place in such a way that at a given moment there are, say two half-full-value voltages on the positive side, and one full-value voltage on the negative side. The net result is zero.

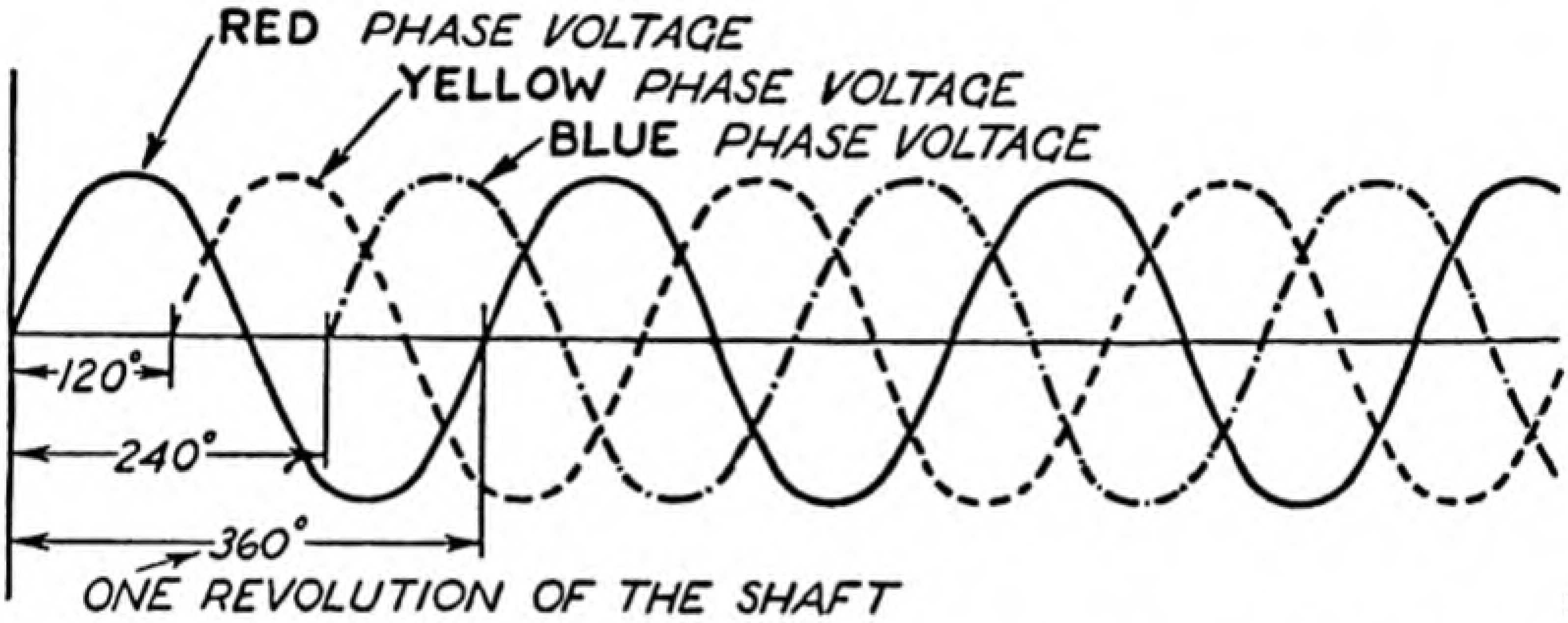


Fig. IV, 2.—The relationship of the three-phase voltages

Thus, if three of the six coil ends are connected together, there will be no resultant current in the connecting links to what is called, when this form of connection is adopted, the star-point, or neutral. If the other three ends are taken out to the external circuit, and are connected to a load which comprises three equal elements (for example three electric radiators arranged with three of their ends connected together to a star-point) then a perfectly workable system emerges.

Fig. IV, 3, shows such a three-phase system. When one "unit" of current is flowing left to right in the red wire, two "half-units" of current are flowing from right to left in the yellow and blue wires.

Three-phase Distribution

The normal three-phase transmission system, as seen almost everywhere in the world, employs only the three phase wires, as they are called. But it is possible to provide a second value of voltage by using a fourth wire.

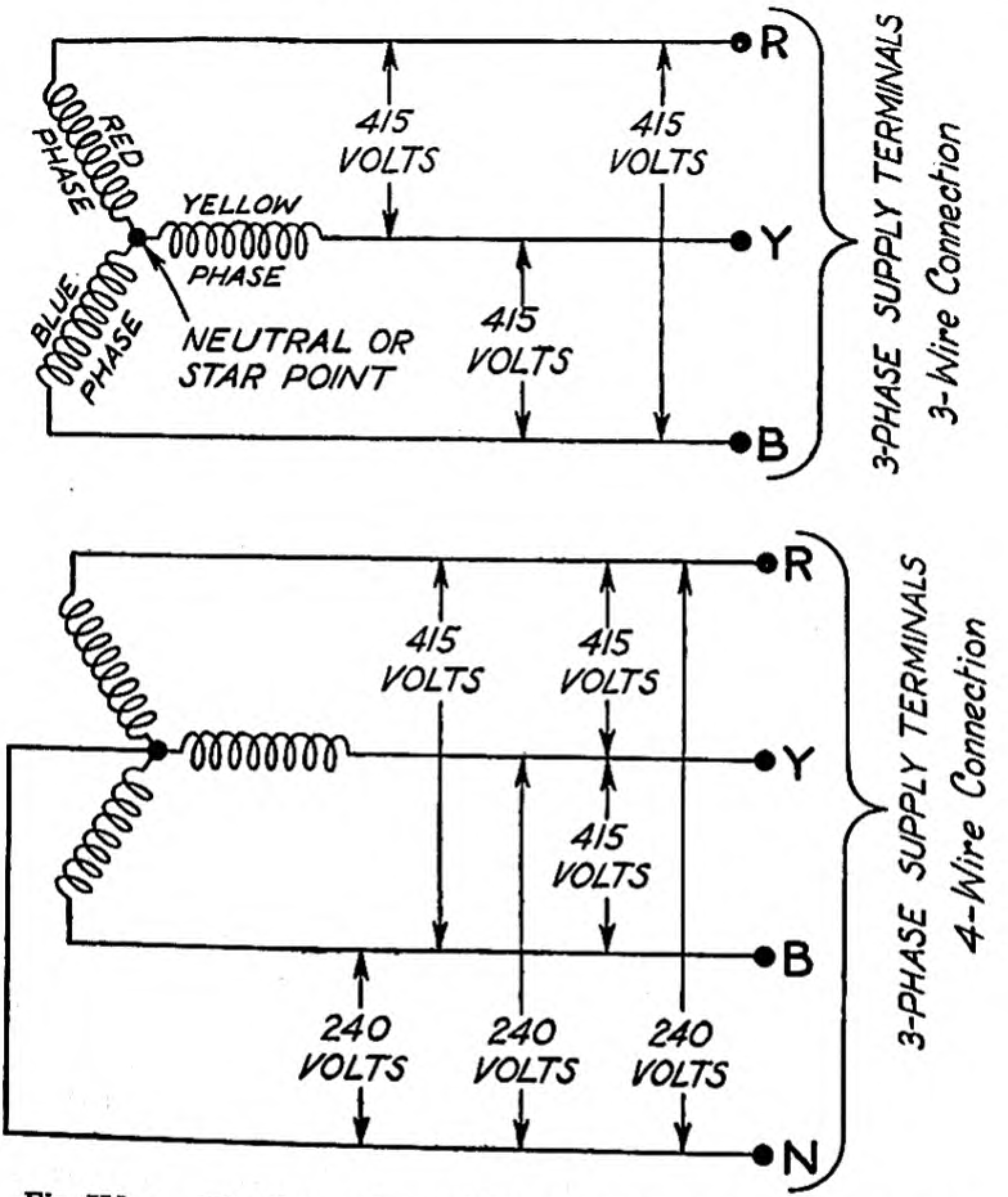


Fig. IV, 3.—The three-wire and four-wire three-phase connections

The voltage between the red and yellow terminals is not the simple arithmetic sum of the voltage generated at any moment in the red coil, added to the voltage at the same moment in the yellow coil. To illustrate why this is so, imagine a truck moving along railway lines and being pulled by two men with ropes. If one man is exerting all his pull along the exact direction of the railway lines, all his effort is usefully employed. But suppose that the second man is pulling at an angle to the track. Only that part of his effort which is usefully directed along the track is of value; mathematically this is called the useful

component and is denoted by the value of his pull multiplied by the cosine of the angle between the direction of his rope and that of the track. To evaluate the sum total of useful pull being exerted on the truck, it would obviously be incorrect to add the whole of his pull to that of the first man.

With this analogy in mind, it will be realized that when two voltages not in phase are to be added together, only that component of the second voltage which is pulling in harmony with the first voltage (to use an unscientific expression) must be added in arithmetically. In point of fact the voltage across two phases of an alternator wound on the three-phase system, where each phase produces 100 volts by itself, is actually 1·732 times 100 volts, or 173·2 volts. If a wire from the neutral point to which all three phases are connected is brought out of the alternator, then the voltage from that wire to each of the phase wires will be 100 volts, while the voltage from red to blue, from blue to yellow, and from yellow to red, will be 173·2 volts in each case. The figures in the diagram in Fig. IV, 3, will be seen to bear this relationship to each other.

For the utilization of electrical energy in factories the three-phase system with the fourth wire brought right into the factory is almost universally employed. We shall see shortly its advantages from the point of view of the alternating current motor; but there are other vital advantages in using the three-phase system instead of just a single phase. These relate to the design of the alternator itself, whereby greater use can be made of the winding space, and also it can easily be proved mathematically that to transmit a given amount of energy over a given distance, less copper is required in the wires if three conductors, connected on the three-phase system, are used, instead of two wires on the single-phase system, or with direct current. (This argument does not however apply automatically to very high voltage long-distance transmission lines where many other considerations have to be taken into account.)

As most alternating current electric motors operate on the three-phase principle, it has been necessary to explain this principle before describing briefly the three-phase motor.

Three-phase Motors

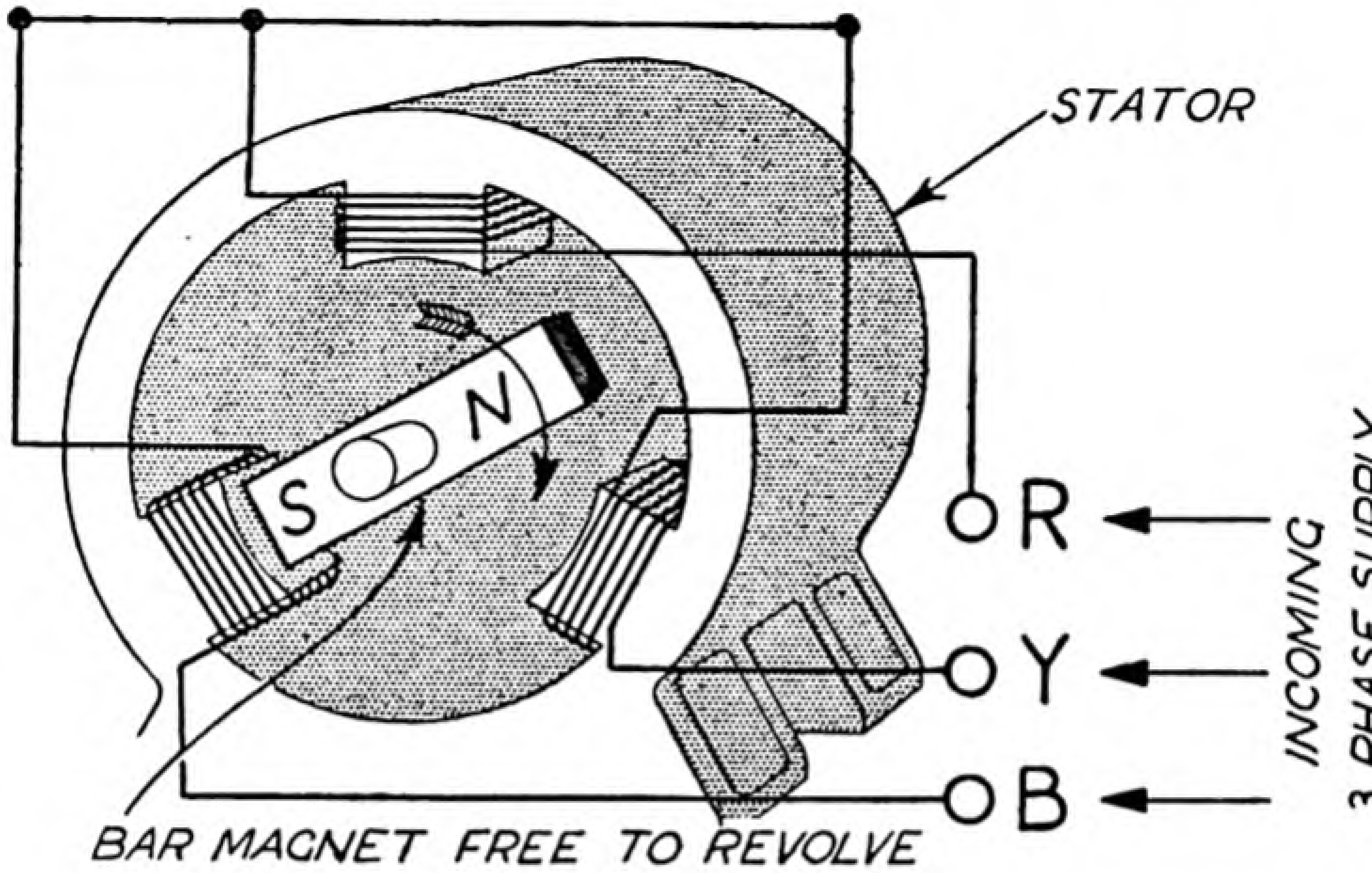
If we now imagine that a stator is provided with three poles, and that these poles have their windings connected to the three phases of the supply (the other ends being joined together at a star-point) we see at once that three magnetic fields, alternating in accordance with

the alternations in the voltage in each phase, will be set up. If a shaft were now placed through the stator and on it were mounted a simple straight bar magnet, the north pole of the magnet would be subjected to a series of attractions from the three poles in the stator as, in turn, they became south poles. Thus it would be subjected to a rotating field, and if free to move will in fact turn round at exactly the same speed as the basic elementary alternator that provides current to the system (Fig. IV, 4).

In practice, however, the rotor takes a different form. If a coil of wire closed on itself to form a loop is placed near an electromagnet (which might be one of the poles of our three-phase motor), currents will be induced in it by the ordinary transformer action. Whenever a coil of wire carries a current it becomes a magnet. Thus, if such a closed coil, perhaps wound on an iron core to assist the passage of the magnetic lines of force, was in fact placed in the position of the rotor of a three-phase alternating current motor the same effect as if a bar magnet were in the same situation would be produced—the coil and its core would revolve.

The majority of three-phase motors are of what is known as the "squirrel-cage" type, a picturesque description used because the assembly of bars parallel to the axis joined to short circuiting rings at each end, has something of the appearance of a squirrel cage, before it is mounted on its iron core. Currents are induced in the squirrel cage by the action of the rotating magnetic field set up by the three poles. If the magnetism caused by the current flowing through the pole windings were set up instantly on the passage of current the motor would not work, since the rotor would instantly revolve by some part of a circle to a point where the instantaneously produced north pole ends of the three magnets set up by the induced currents in the rotor were directly opposite their corresponding south poles, and there would be no inducement for the rotor to turn any farther. But, in fact, the magnetism is out of phase with the current owing to the time taken to build up the magnetic field and thus the magnets created on the rotor lag behind the rotating magnetic field set up by the stator. To put the matter again somewhat unscientifically, any one "magnet" on the rotor is always trying to catch up with its opposite number on the stator, which, however, moves on as the three-phase cycle progresses. For this reason, the speed of the rotor of a squirrel-cage motor is not in fact the same as that of the alternator feeding the three-phase system. It is usually about 10 per cent lower and this difference in speed is known as the "slip".

There are types of motors that run at a speed exactly proportional



MAGNET REVOLVING IN A 3-PHASE MAGNETIC FIELD

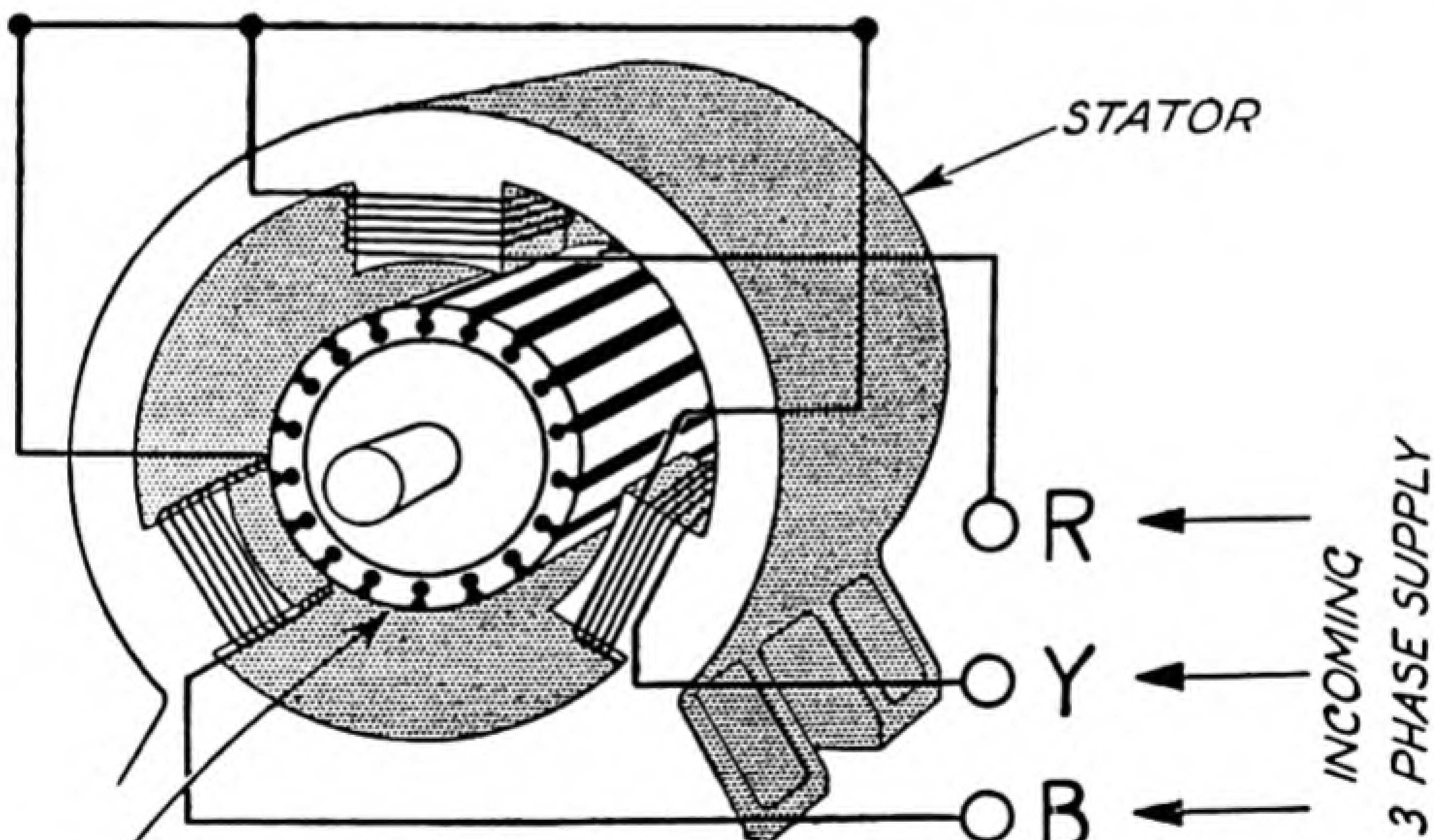


Fig. IV, 4.—*Above:* the principle on which the three-phase motor is based. *Below:* the squirrel-cage type motor, which is the most widely used of all types of electric motive power

to the system frequency, and they are known as synchronous motors. When a motor does not run at this synchronous speed, it is known as an asynchronous motor, and the squirrel-cage induction motor, to give it its full title, is of the latter type.

Other A.C. Motors

There are many other kinds of alternating current motor besides the simple squirrel-cage type. The single-phase motor can take a number of forms. When only a single phase is available from the supply —and this of course is the case on ordinary domestic premises—the designer faces the problem of providing a rotating magnetic field to drag round the rotor, as is done for him automatically in the case of the three-phase system.

This problem is solved in two ways. The first is to use exactly the same kind of motor as for direct current, equipped with a commutator and brushes. If, in the basic direct current motor, the field was not a permanent magnet but an electromagnet connected in series with the armature without a commutator the direction of current in both elements—the fixed and moving parts of the motor—would change at the same time. Thus the vital element in the creation of rotary motion —a change between the magnetic state of the stator and that of the armature would not be effected as both would change together. The commutator prevents this happening, and so the motor will run.

Certain small single-phase a.c. motors are operated on this basis ; but there are technical problems which make it difficult although not impossible to design large motors in this way. In consequence, other means have to be found.

Bearing in mind that the basic problem is that of providing a rotating field, designers of single-phase a.c. motors create an artificial second phase by providing the stator with four poles instead of two. The two main poles carry a winding connected to the supply. Tapped off the supply in addition there is also a second winding which includes in its circuit a capacitor or an inductance which has the effect of altering the phase in relation to the phase of the supply (the effect of capacitance and inductance is explained in Chapter V. In this way a rotating field, which is in effect of a two-phase kind, can be created.

There are also a.c. motors, generally of the larger horsepowers, in which the squirrel-cage type of rotor is replaced by a wound rotor, the ends being brought out to slip rings to which resistances are connected. The squirrel-cage motor cannot change its speed; it runs at a constant slip speed a little less than the speed fixed by the frequency of

the system; its speed is "geared" to the system's speed or frequency. In the case of the slip-ring motor, when resistance is introduced into the closed circuit of the rotor coils, the slip may be varied so that the speed of the motor will also vary to a limited extent.

Another type of motor is the synchronous motor, where the design is in effect equivalent to a simple permanent magnet spinning on its shaft within the stator enclosure. Instead of the magnet, however, there is a wound rotor supplied with direct current so that it takes up the condition of one or more permanent magnets, and as there is no delay in this case in creating the induced magnetism in the rotor, the motor will run at exactly and precisely the speed of the original alternator supplying the system. This type of machine has the complication that it needs a direct current supply for its excitation circuit, and thus it is obviously more costly; but there are good reasons for employing motors of this type for many large drives in industrial installations.

Electro-chemical Effects

We briefly mentioned earlier that an electromotive force may be generated electro-chemically, by placing two dissimilar metals in a jar of acid. One becomes positive and the other negative. This might be described as the "forward" electro-chemical process where the result of an electro-chemical action is to produce electromotive force; the "reverse" effect is for electromotive force, resulting in the passage of current, to create an electro-chemical effect (Fig. IV, 5).

The chemical effects of the electric current have therefore two clear divisions—those in which the electro-chemical cell acts as a generator, the chemical energy issuing from the reaction being converted into electrical energy, and those in which electrical energy is applied from an external source and results in a chemical reaction.

In the first class are primary cells, or batteries. The most commonly used is the Leclanché cell, in which the electrodes are carbon and zinc immersed in acid solution of ammonium chloride, or, as it is commonly known, salammoniac. This cell will produce a voltage of about 1½ volts, and a current up to about 1 ampere, depending on the size of the carbon and zinc electrodes.

The difficulty that arises if primary cells, particularly the Leclanché cell, are to be used for producing appreciable amounts of power, is polarization. As the current passes through the electrolyte it decomposes the acid, and hydrogen is produced round the positive carbon electrode. This has the effect of creating an electromotive force in the reverse direction, opposing that produced by the cell itself, and thus the

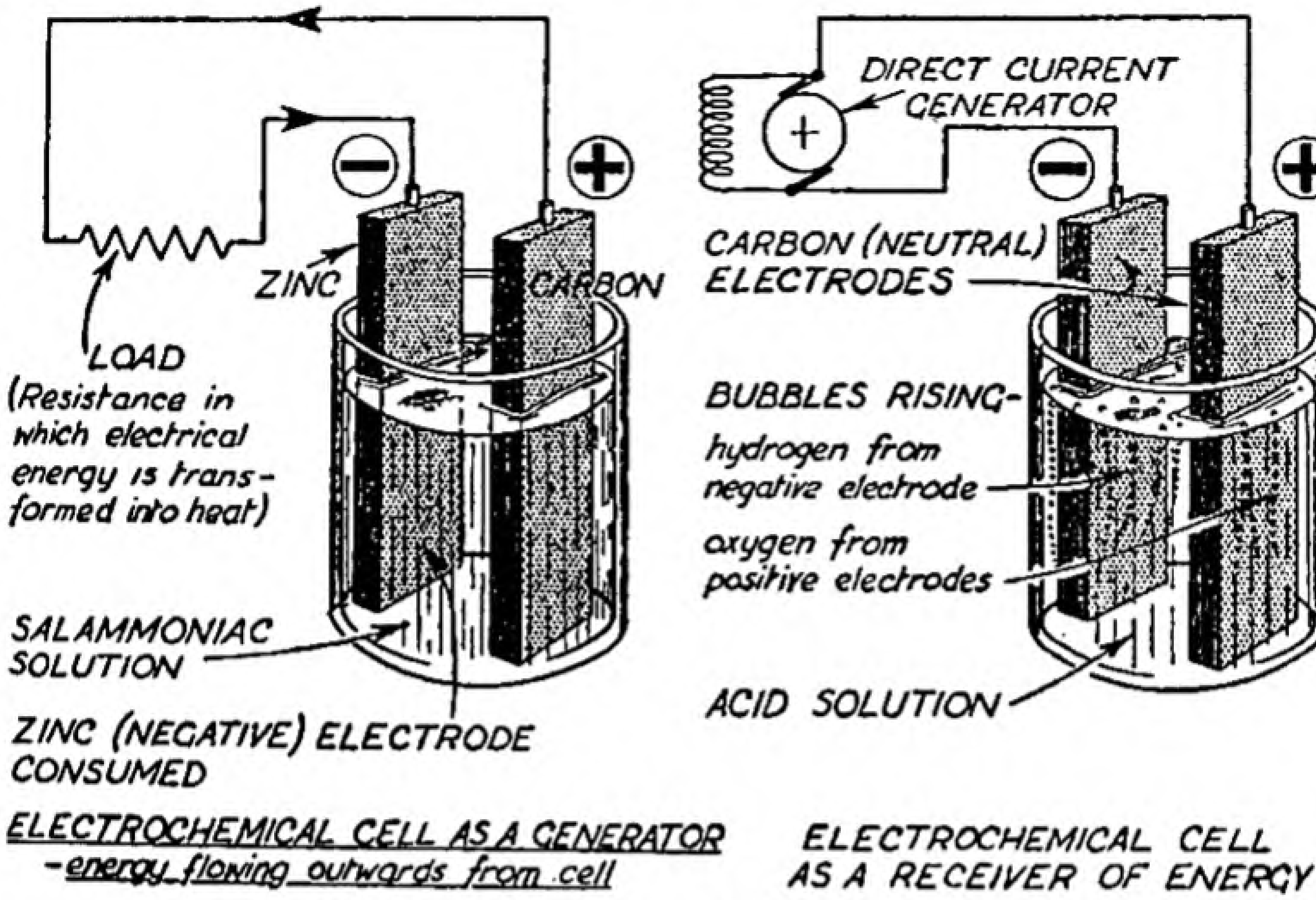


Fig. IV, 5.—The electro-chemical cell in its two forms

voltage output (and consequently the current flowing in the circuit) will decrease considerably after a short period of use. To counteract this effect a depolarizing agent is used to absorb the hydrogen gas accumulating round the carbon electrode, and is known as a depolarizer. This usually consists of manganese dioxide and fine carbon granules, for the purpose of trapping the gas in their pores, so that it can be acted on by the manganese dioxide.

Wet and Dry Batteries

The Leclanché cell is made up in two forms—the wet cell and the so-called dry cell (Fig. IV, 6).

The wet cell is a glass jar holding the electrolyte and coated externally with an acid-resisting bitumen paint to prevent creepage of electrolyte over the side and consequent corrosion to the base on which the cell is mounted. The negative electrode is a zinc rod usually about half an inch in diameter, with a copper wire soldered to the top portion for connection to the circuit. The positive electrode consists of a carbon rod or slab, mounted in a porous porcelain container in which the depolarizer agent is packed.

This type of cell is employed for such duties as ringing electric bells where no mains supply is available, and cells of this type will

give satisfactory service on intermittent duty for many months before renewal is needed first of the electrolyte, secondly of the zinc rod which is consumed, and finally of the positive electrode (which is itself not consumed, though the depolarizing agent is). A number of cells are connected in series, that is to say, the negative terminal of one is joined to the positive terminal of the next, and so on, the voltages adding up until the required potential is reached.

These cells would only be used for power purposes under extremely unusual conditions, as the cost of producing electrical energy in this way is between ten and twenty times as great as the normal cost of purchasing energy from the supply authority. The supply of power for railway signals and points, in isolated districts, is a case where these batteries are usefully employed.

The second form in which the Leclanché cell is made up is known as the dry type, and this represents the greatest output of the battery manufacturers, since hundreds of millions of individual cells are used each year for such purposes as torch batteries, "high tension" batteries for portable radio sets, batteries for hearing aids, and indeed all applications where a portable source of electric current, of very low power, is needed.

The dry cell usually consists of a cylindrical zinc outer casing, which acts as the vessel containing the whole cell and also as the negative electrode. The positive electrode is a carbon rod which is packed round with its depolarizing agent, and wrapped in porous cloth while the electrolyte is in the form of a paste containing the salammoniac solution.

The dry cell has been developed to a high state of efficiency but suffers from the disadvantage that it will gradually become useless if stored for lengthy periods, because the paste electrolyte tends to dry out. Cells of this type can be made in very small sizes, sometimes of almost microscopic proportions. As the voltage produced by the electro-chemical action is the same whatever the size of the cell, a battery made up of 100 very small cells permanently joined together will obviously produce 150 volts, although of course the current that can be drawn will be very small.

Another type of Leclanché cell, very similar to the dry battery, is the inert cell, the main difference being that as the cell is manufactured it is completely dry, the top being sealed by a removable plug. Thus it does not deteriorate on the shelf and when it is needed all that is necessary to activate it is to remove the plug and fill up with water.

A second type of primary cell used occasionally in the laboratory is the Daniell cell, in which zinc is again used as the negative electrode

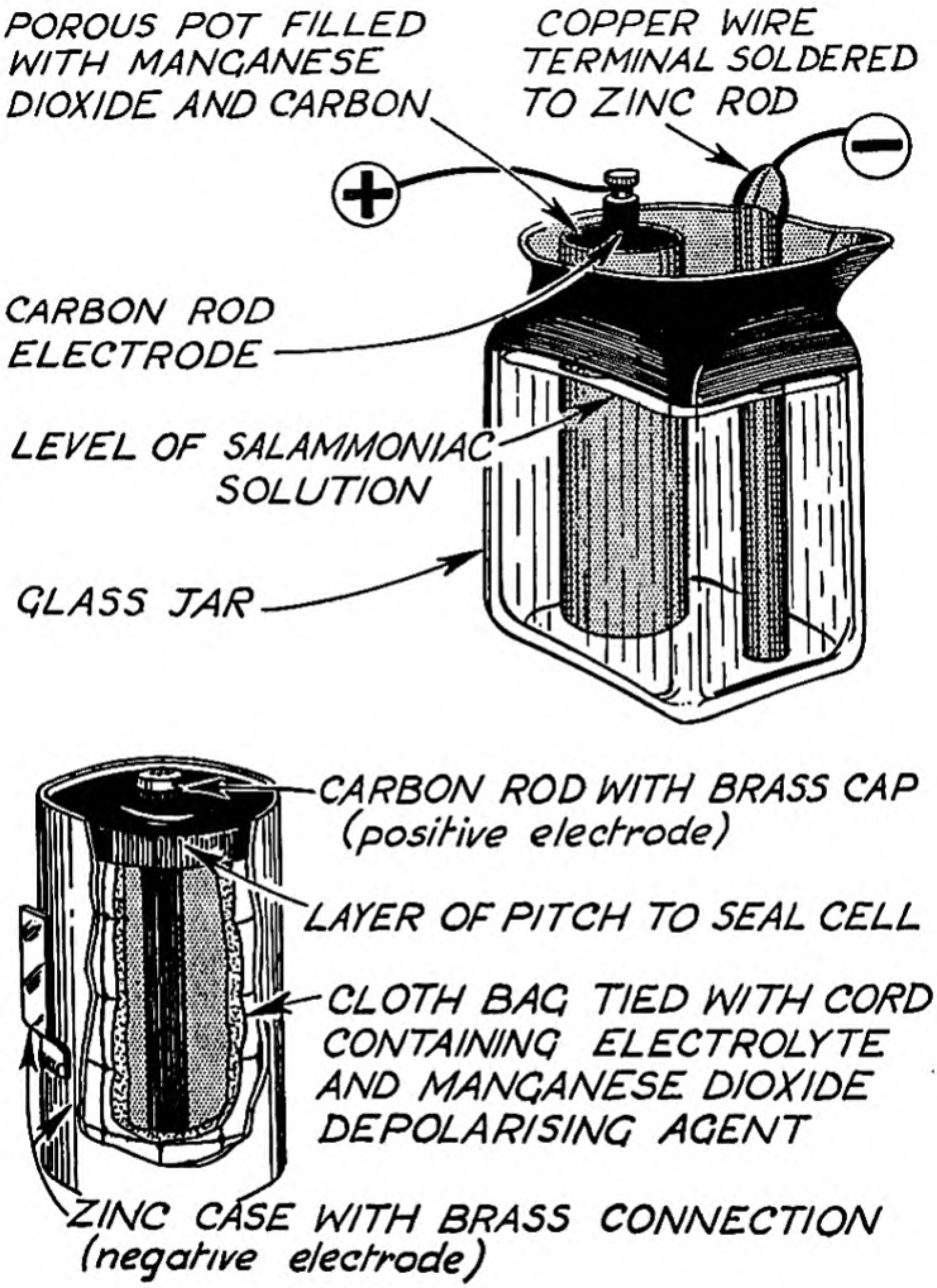


Fig. IV, 6.—*Above*: the "wet" form of the Leclanché cell
Below: the dry form of the same cell

with copper as the positive electrode, both of these being immersed in sulphuric acid. In practice the zinc rod is situated in a porous earthenware pot which contains the acid, and the copper electrode stands outside, in the glass vessel which is filled with copper sulphate solution, this acting as a depolarizer. The electromotive force of a Daniell cell is about 1 volt.

There is a number of other combinations of metals which may be used, with various electrolytes; and in general metals are graded in what is known as the electro-chemical series, which includes elements which are not metals, as well as the whole range of metallic substances. Hydrogen is at the top of the table and carbon is at the bottom. There are possibilities of forming a primary cell by using any two substances that differ in what is called their electro-chemical equivalents, or their place in the electro-chemical series. In practice however, there are various difficulties in the way of using, on a practical scale, any other substances than those indicated above for the Leclanché and Daniell cells.

Storing Electrical Energy

One of the principal problems which has always faced the electrical engineer is that of storing energy. Consumers are at liberty to switch on the lights and fires and radio sets in their homes whenever they wish, and in the absence of any method of storage the power station must supply this load as it arises. This leads to uneconomic operating conditions, and no large-scale solution has yet been found. Thus, storage batteries, or, as they are commonly known, accumulators, have an important role to play, but have never been developed into the large-scale efficient energy storage devices for which engineers have always hoped, and they are not used in connection with public electricity supply systems.

Nevertheless the accumulator plays an extremely important part in providing a source of energy for such purposes as starting the engines of vehicles and boats, providing portable power on a relatively small scale wherever it is needed, providing standby power for such purposes as emergency lighting in cinemas and other buildings in the event of mains failure, for providing the basic low voltage direct current power needed by telephone exchanges, railway signalling systems, the control circuits of electric power plants, and the supplies needed for portable radio and television transmitting equipment.

There are two forms of storage battery—the lead-acid type and the alkaline type.

We have seen that if different metals are immersed in the same bath of acid, there will be an electromotive force between them. In the case of the metal lead, one of the compounds of the metal with oxygen, known as lead peroxide, can be used in conjunction with the plain metal lead itself to produce an electromotive force. If two plates of plain lead are immersed in acid, and a current is then passed between them from an external direct current source, the effect will be to produce an electro-chemical reaction at the negative terminal so that the lead is changed to lead peroxide. If the charging current, as it is called, is now removed there remains a potential primary battery, since there are now two different metals with a potential difference being created between them. Thus, the cell is now capable of delivering back to an external circuit some considerable proportion of the energy originally put into it during the charging process. (The chemical explanation here has been considerably over-simplified, although the basic principle is correct.)

In practice the lead-acid accumulator takes the form of a glass or plastic container which carries stacks of positive and negative plates which are interleaved (Plate 12). The battery produces about 2 to 2·25 volts for each cell, and consequently for a typical car starter battery six cells would be necessary to produce the nominal 12-volt output employed for such purposes. To increase the current, which in the case of an ordinary motor-car may reach as high as several hundred amperes at starting, a large number of plates in each cell is connected in parallel—that is to say all the negative plates are connected together to one terminal and all the positive plates to the other.

The plates themselves take the form of lead grids which are different for positive and negative, and have different constructions when made by different makers. The positive plate is often a cast grid and the negative plate is another grid of different design, into the pores of which spongy lead-oxide powder has been forced. Between the plates, to separate the positive and negative voltage areas from each other, are separators which used to be made of wood but are now of plastic grid or crimped-plate form. The electrolyte is diluted sulphuric acid.

The second form of storage battery uses either nickel and iron or nickel and cadmium as the electrodes, and an alkaline solution instead of acid as the electrolyte. This usually takes the form of potassium hydroxide—dissolved caustic potash (Plate 13).

The disadvantages that have always faced the lead-acid cell designer relate to the weight of the cell (owing to its lead content) for a given output and also its relative lack of mechanical strength, since the container might be broken by severe vibration and the paste can be

shaken out of the plates under severe conditions. The alkaline batteries have the advantage that the container itself may be made of steel and can form one of the electrodes, although in practice there are iron electrodes as well as the corresponding nickel or cadmium electrodes, more or less of the same form as those used for the lead-acid battery. With its steel case the alkaline battery is obviously more robust than the lead-acid battery and it has the further advantage that owing to the stronger mechanical construction of the plates themselves it does not suffer from difficulties due to buckling of plates when very heavy discharges have to be conveyed. It is, however, not without its own disadvantages, since the voltage per cell is only 1·5 volts and consequently more cells are needed for a given voltage, and its first cost is considerably greater.

Electrolysis

In the second main aspect of the chemical effects of the electric current, current is passed into some form of electrolytic cell to produce a desired chemical effect. The simplest example is the electrolysis of water. If two electrodes are placed in a jar of acidulated water and a current is passed through, the result will be a splitting up of the molecules of the water (which is of course composed of hydrogen and oxygen in the proportion of two atoms of hydrogen to one of oxygen) into their constituent parts. Hydrogen is formed at the negative electrode and oxygen at the positive electrode, and these gases, which bubble up through the liquid, can be collected and stored. If another electrolyte, instead of water, is used, for example brine, which is a solution of sodium chloride, then the application of electric current will result in the production of chlorine. Many gases may be produced in this way, and very large amounts of low voltage direct current electrical energy are used for this purpose.

The electrolyte in certain cases may take the form not of an ordinary liquid but of a molten bath of such substances as aluminium ore. A carbon electrode immersed in such a molten bath is used as one pole and the metal itself forms the other. Pure aluminium, free from its impurities and from its combination with other elements in the ore form, is deposited on the carbon cathode. In such countries as Norway, where there are vast reserves of aluminium ore, and in Canada, enormous hydro-electric stations have been built to devote the whole of their outputs to ore-processing electro-chemical cells of this type.

Among the most widely used electro-chemical processes is that of electro-plating. A large variety of metallic objects used in everyday

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CHAPTER V

BASIC LAWS

BEFORE an electric current can flow in any sort of circuit, there must be an electromotive force, or voltage, to "push" the current along; and the amount of current that will flow and the consequent amount of energy that will be transformed into heat, light, mechanical energy or chemical energy in the various parts of the circuit will be conditioned by the manner in which the various parts of the circuit are connected together.

The first basic law has already been stated (page 18), i.e. Ohm's Law, which tells us that the current in a straightforward direct current circuit is proportional to the voltage applied and inversely proportional to the resistance between the terminals.

A circuit may be made up of a number of resistances, and these may be connected in one of two main ways—in series or in parallel (Fig. V, 1). Series connection (sometimes known as cascade) means that these resistances are connected end to end, like a string of sausages. In this case the total resistance is the arithmetical sum of the individual resistances. A simple example will illustrate this.

Suppose resistances of 10, 30 and 40 ohms are joined in series across a 100-volt battery. The total resistance will be $10 + 30 + 40 = 80$ ohms, and consequently the current will be:

$$\text{Current (in amps)} = \frac{\text{Voltage (100)}}{\text{Resistance(80)}} = 1{\cdot}2 \text{ amperes}$$

The general formula is that the resultant resistance $(R) = R1 + R2 + R3$.

Connection in parallel means that each resistance is individually connected across the poles of the battery. In this case, the more paths there are for the current to take, the more total current will flow. Thus, adding resistances in parallel *decreases* the total resistance,

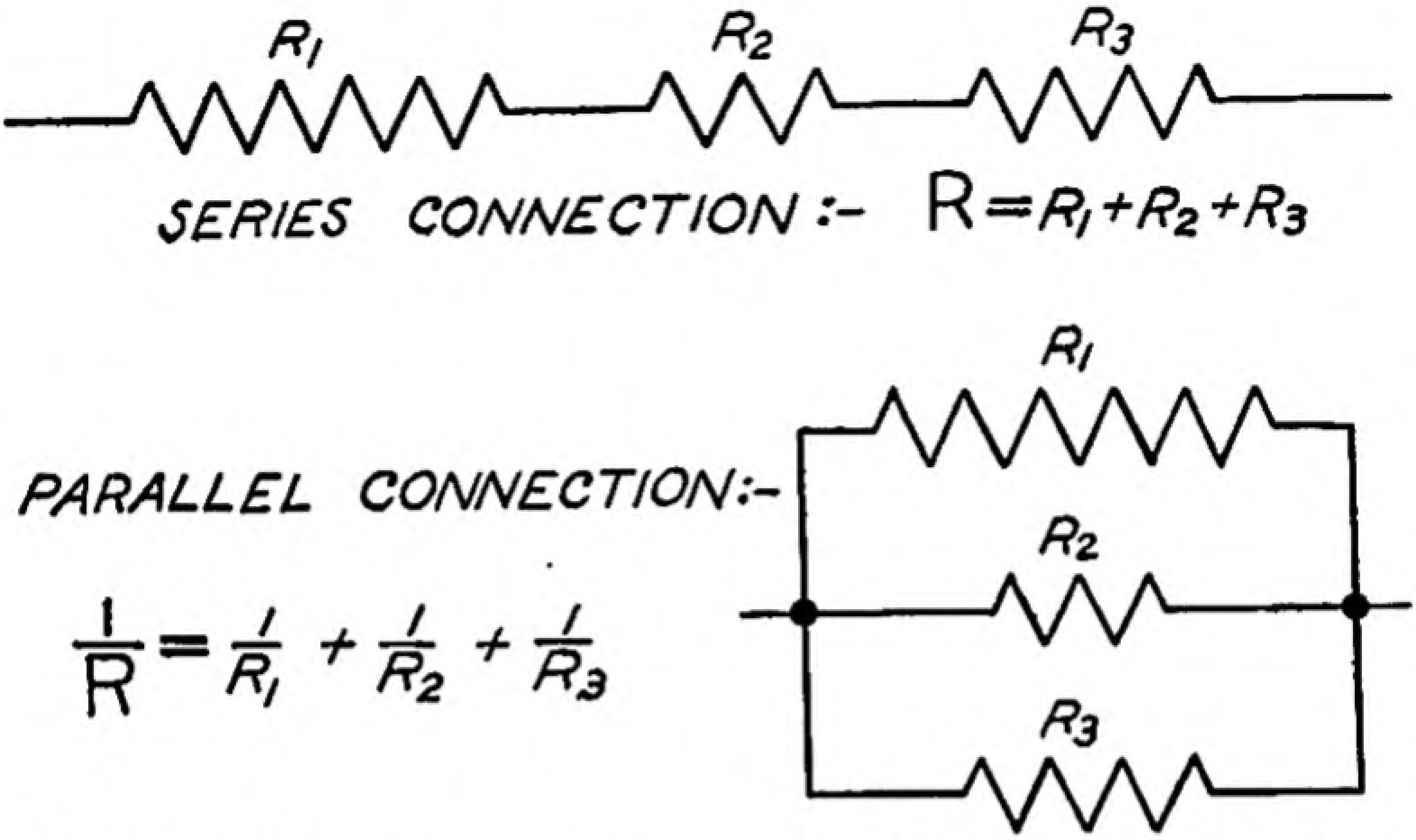


Fig. V, 1.—The series connection (*above*) and the parallel connection

whereas adding them in series *increases* the total resistance, and diminishes the current.

If a single resistance was connected across the poles of the battery a certain current would flow, depending on the value of the resistance. If a second resistance of exactly the same value was added in parallel with the first, twice the current would flow, or, in other words, the resistance would be halved. A simple arithmetical relationship enables us to find the resultant resistance (R) of a number of resistances joined in parallel. It is

$$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

To take an example, suppose that resistances of 20 ohms, 15 ohms, and 12 ohms are connected in parallel across our 100-volt battery. The formula would then become

$$\frac{1}{R} = \frac{1}{20} + \frac{1}{15} + \frac{1}{12} = \frac{12}{60}$$

and consequently $R = 5$ ohms, and the current will be $\frac{100}{5} = 20$ amperes.

A circuit may consist of a number of elements some of which comprise series, groups and the other parallel groups, while the series

groups may be in parallel themselves with other groups. To find the current that will flow in circuits of this type, it is necessary first to work out the equivalent resistance (the single resistance that would take the place of, and have the same effect as, the group under consideration) for each separate part. In this way the circuit can rapidly be reduced to a single equivalent resistance, and the current can be calculated.

When alternating current flows in a circuit, there are considerations other than those relating to simple resistance to be taken into account. In the section on alternating current motors (page 55) we showed that there could be a phase difference between two voltages. It is a little more difficult perhaps to appreciate that in a single alternating current circuit there may be a phase difference between the current in the circuit and the voltage producing it.

This can perhaps be appreciated by means of the analogy of the man or men drawing a railway truck. If one man starts to pull a railway truck along a railway track, and his rope is in effect a rigid steel wire (which we will suppose cannot possibly be stretched), then at the instant when he begins to pull, the whole of his pull is communicated to the truck. But if his rope is an elastic cord the pull during the first instant would not be transmitted to the truck at all: the man's effort would be taken up in stretching the rope, or in other words in storing some of the energy he has exerted in the elastic of which the rope is made. Only when he had stretched the rope to its fullest extent would the pull be communicated to the truck. If instead of pulling with a regular, unvarying, steady pull, he exerted his efforts in a sort of pulsating pull, which might perhaps correspond to every step forward he took along the track, the tugs exerted on the truck would occur a little later than the instant when the man's effort was at its maximum. In electrical terms, there would be a phase difference in time between the pull and the result.

With this analogy in mind, let us consider what happens to a voltage applied to a coil of wire surrounding an iron core, or even to a coil of wire by itself. Immediately current starts to flow on, let us say, the first positive half-wave, a magnetic field starts being set up by virtue of the basic relationship between electric current and magnetism. We have seen that when any coil cuts a magnetic field an electromotive force is generated. In practice the coil cuts its own field (Fig. V, 2), and the electromotive force so generated acts in opposition to the main electromotive force applied from outside and thus delays the setting up of the full current which should flow according to an ordinary Ohm's Law calculation. This means that the current flowing in what is known as an inductive circuit—a circuit where the current flows

through a coil which can cut its own lines of force—is always *behind* the voltage producing it, in phase.

In the case of a highly inductive coil, where there are many thousands of turns, perhaps wound on an iron core so that the magnetism can have the easiest possible path, the inductive effect is so great that the current lags behind the voltage producing it by 90°, a quarter of the circle representing a single complete cycle of the alternating current wave (Fig. V, 3). This means that when the voltage wave, starting from zero, reaches its first full maximum point, the current

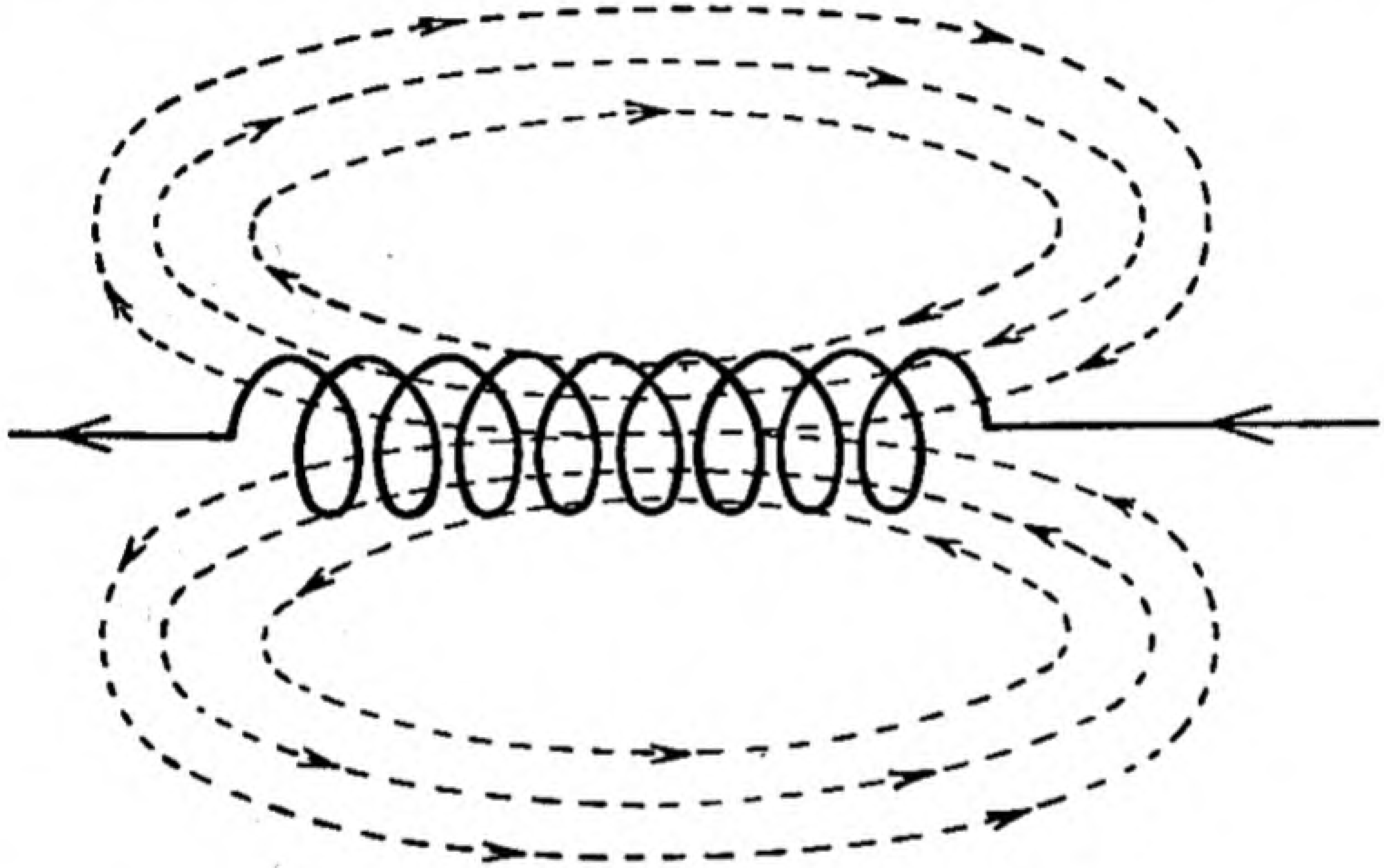


Fig. V, 2.—The action of self-induction

will only just be starting to flow, and maximum current will flow when the voltage wave has once more reached zero, on its way to maximum negative.

Impedance

In addition to this effect of bringing the voltage wave and the current wave out of phase with each other, an inductive circuit has the effect of offering additional "resistance", since energy is expended in such a circuit not only in the creation of heat in the conductors, as in a direct current circuit, but also in feeding out magnetic energy into the magnetic field set up by the coil. Thus, we do not speak of the resistance of an inductive circuit fed by alternating current, but we use the term impedance to denote the combined effect of simple resistance and the effect of the inductance.

If there is any doubt as to this difference between the "opposition" offered to the passage of an electric current between the a.c. and d.c. systems, it may perhaps be resolved if it is realized that when a direct current supply is switched on to an inductive circuit, there is at the moment of switching on this same "back electromotive force" effect as with alternating current; but once the current has reached a steady value (and this usually takes place in much less than a thousandth part of a second) then there is no question of a further back electromotive force effect, because the coil is not being cut by *varying* magnetic

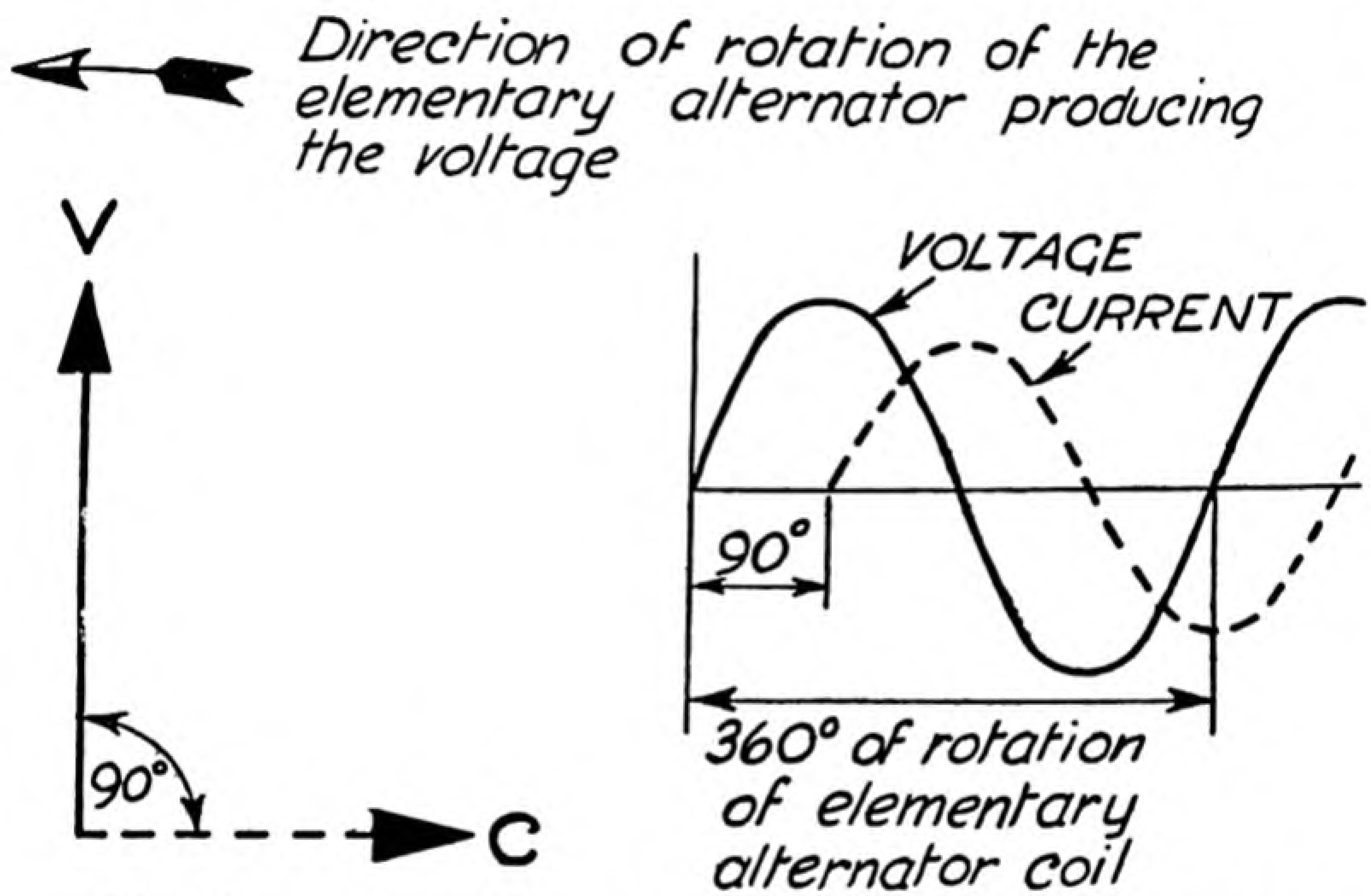


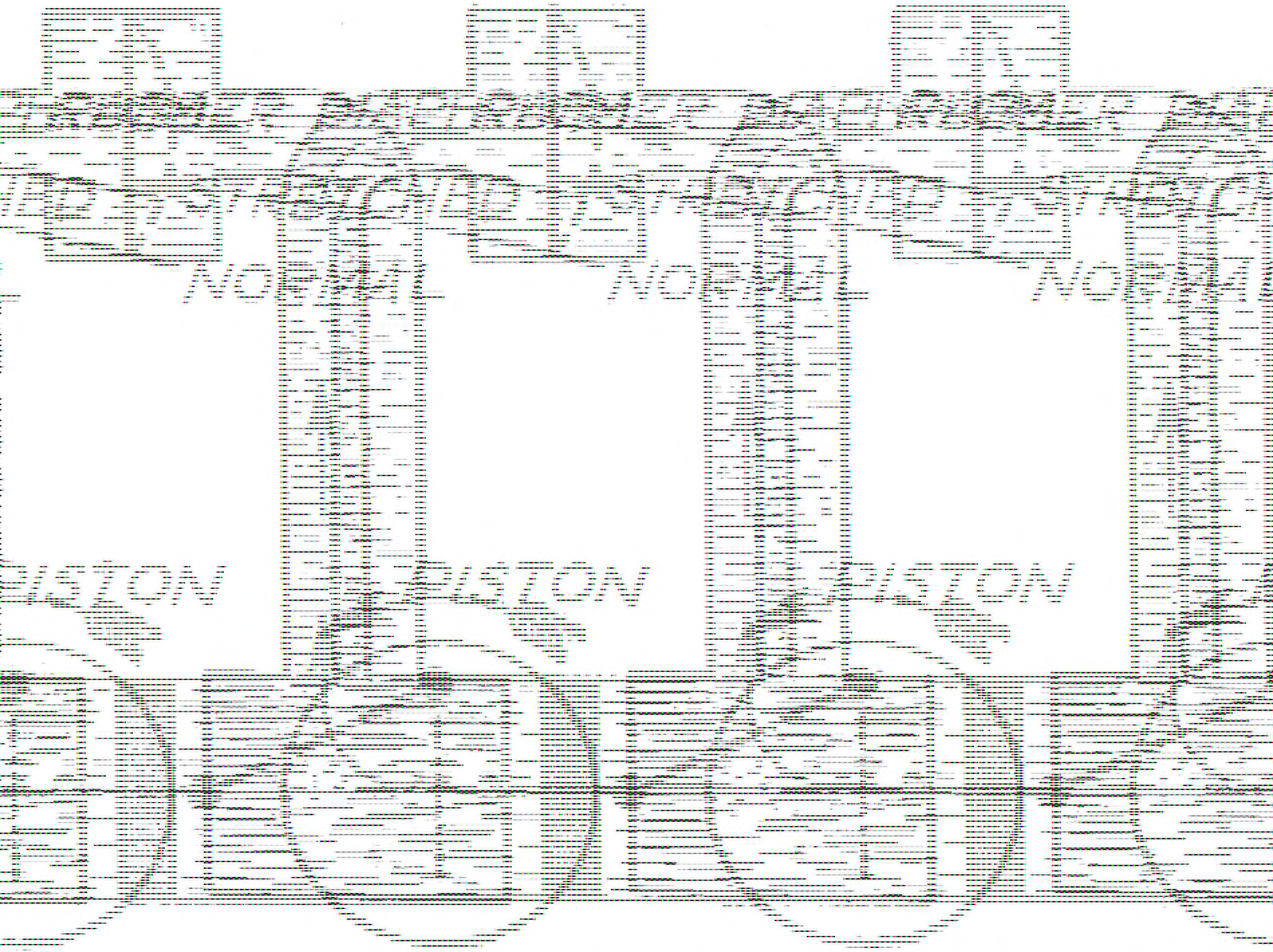
Fig. V, 3.—The voltage and current in an inductive circuit

fields, as it is in the case where an alternating current is flowing, with its constant reversal of the direction of current flow.

Only one factor—temperature—causes a variation in the resistance of a conductor, which is otherwise the same whatever the frequency of the alternating current passing through (except at very high frequencies). But the impedance offered by an inductance varies with the frequency. The higher the frequency the greater the opposition to the passage of current.

Capacitors or Condensers

The third characteristic of electrical apparatus affecting the flow of current is the phenomenon known as capacitance. This is a property of capacitors (or, as they were formerly called, condensers).


NORMAL
PISTON

polarity) reaching the first plate of the capacitor is to charge it up with an amount of electrical energy dependent on the size of the plate. The opposite plate has induced on it a corresponding amount of negative charge. As the alternating current voltage wave begins to change its direction, this positive charge accumulated on the first plate of the capacitor discharges back into the circuit before the alternating current wave has had time to complete its change of direction. Thus there is a pulse of current in *advance* of the voltage. In other words, the current is 90° *ahead* of the voltage producing it, in a purely capacitative circuit, just as it is 90° *behind* the voltage in a purely inductive circuit.

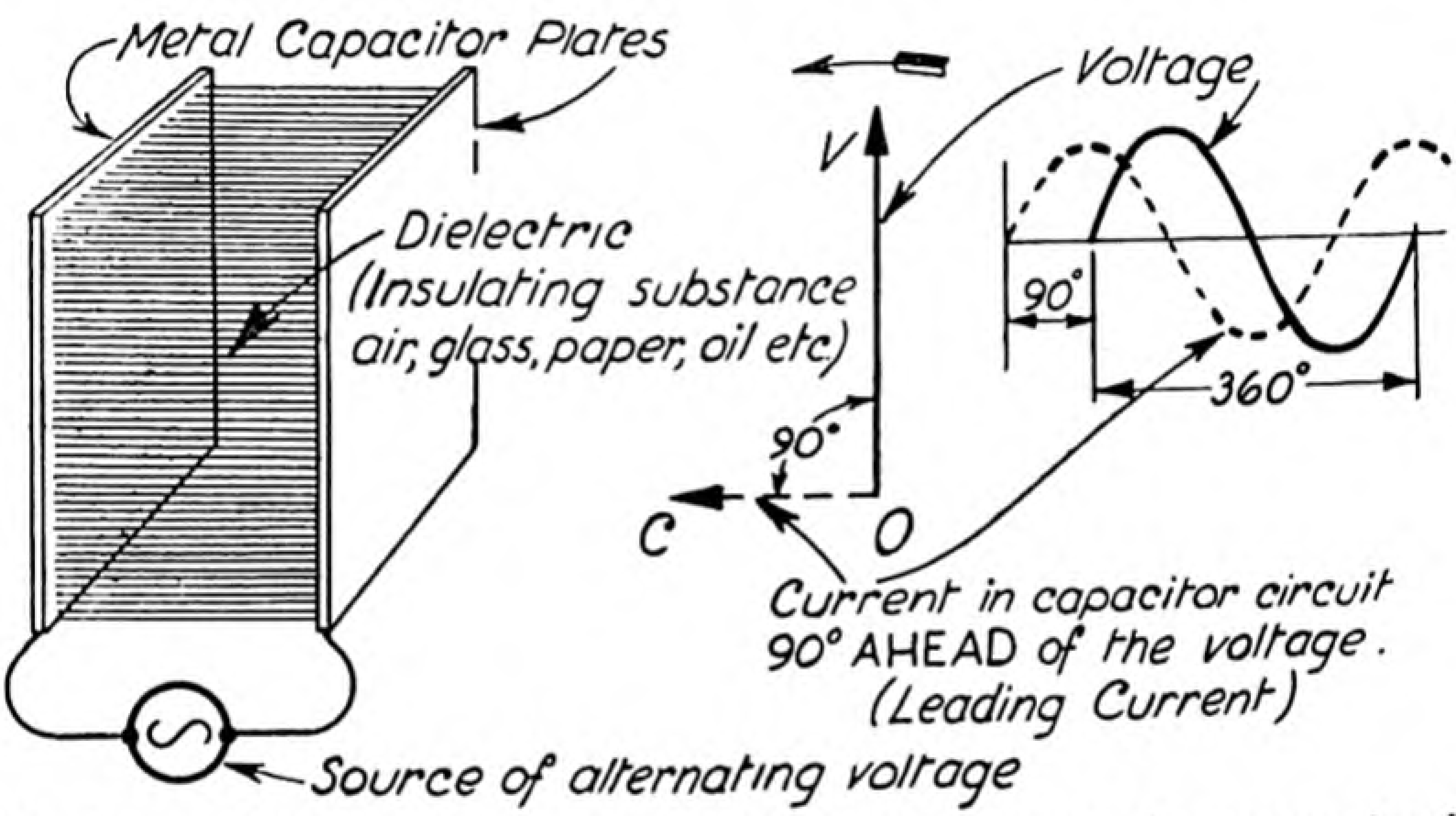


Fig. V, 5.—The capacitor, and its effect on the current in an a.c. circuit

The value of the capacitance of two plates situated as indicated in Fig. V, 5, depends on the size of the plates, the spacing between them, and the nature of the dielectric. The impedance of a capacitor changes with frequency, unlike straightforward resistance. The higher the frequency, the less opposition offered to the passage of current. In high-frequency radio circuits capacitors are very widely used to set up the circuit conditions necessary to direct high-frequency currents in one direction and low-frequency currents in another.

Capacitors are made up in many forms. For radio work a common form is the tubular shape, in which the two "plates" consist of strips of tinfoil separated by a strip of paper, the three strips being wound up together to form a bobbin. Another common form is the electrolytic capacitor. This consists of two "plates" of aluminium (actually specially shaped electrodes) in an electrolyte which is usually of boric acid. The outer can, of aluminium, may form one electrode. An aluminium

oxide film forms on the electrodes and becomes a very thin dielectric, giving a large capacitance value in a small volume. If used on d.c. circuits (as in the smoothing circuit on the h.t. supply in a radio set) these capacitors can only be used in one direction, as otherwise electro-chemical action sets in and destroys the oxide film, causing a short circuit.

Power Factor

When the current is completely in phase with the voltage producing it (as in a resistive circuit) the whole of the current is performing useful work, and this condition is described as "100 per cent, or unity, power factor". If the current lags or leads behind or before the voltage, the power factor is less than unity, and more current is flowing in the circuit than is necessary for the purpose in hand.

Returning to the analogy of the man pulling a railway truck (p. 72), suppose two men (representing respectively the voltage and the current) were pulling the truck by means of unstretchable ropes. If both men pull *along* the line of the track, the efforts they both expend are fully useful. If one man (the current) pulls *at an angle to the track*, only a proportion of his effort, the component lying along the track, is useful. The greater the angle made with the track by his rope, the less the useful effort he expends.

If this angle is considerable, the corresponding electrical condition is called bad power factor, and steps (such as inserting capacitors to compensate for the inductance) must be taken to correct it; otherwise the mains will have to carry excess current, and the copper in them will not be economically employed.

Selection of Wiring

Suppose it is a matter of connecting up a two-bar electric fire to an existing wiring installation, perhaps by a flexible cable from a plug. If too thin a wire is used—and the word "thin" naturally applies to the actual conductor and not to the complete flexible cable with its outer covering—what will be the result? At 240 volts a current of about 8 amperes has to flow in the radiator elements if they are to give out the full heat for which they are designed. This current flows because the resistance of the circuit, from the mains through the flexible cable, through the radiator elements and through the return cable back to the mains, has a certain value. A given voltage will force a given current through this resistance.

If an added resistance is now introduced by the use of a flexible cable which is too thin, some of the potential difference between the two poles of the mains will be dissipated across the resistance of the cable, instead of wholly across the resistance elements in the radiator (Fig. V, 6). Thus the radiator will not get as hot as it should, and the flexible cable *will* get hot, which is undesirable and may be dangerous.

If the flexible wire gets too hot, it will either set fire to the outer

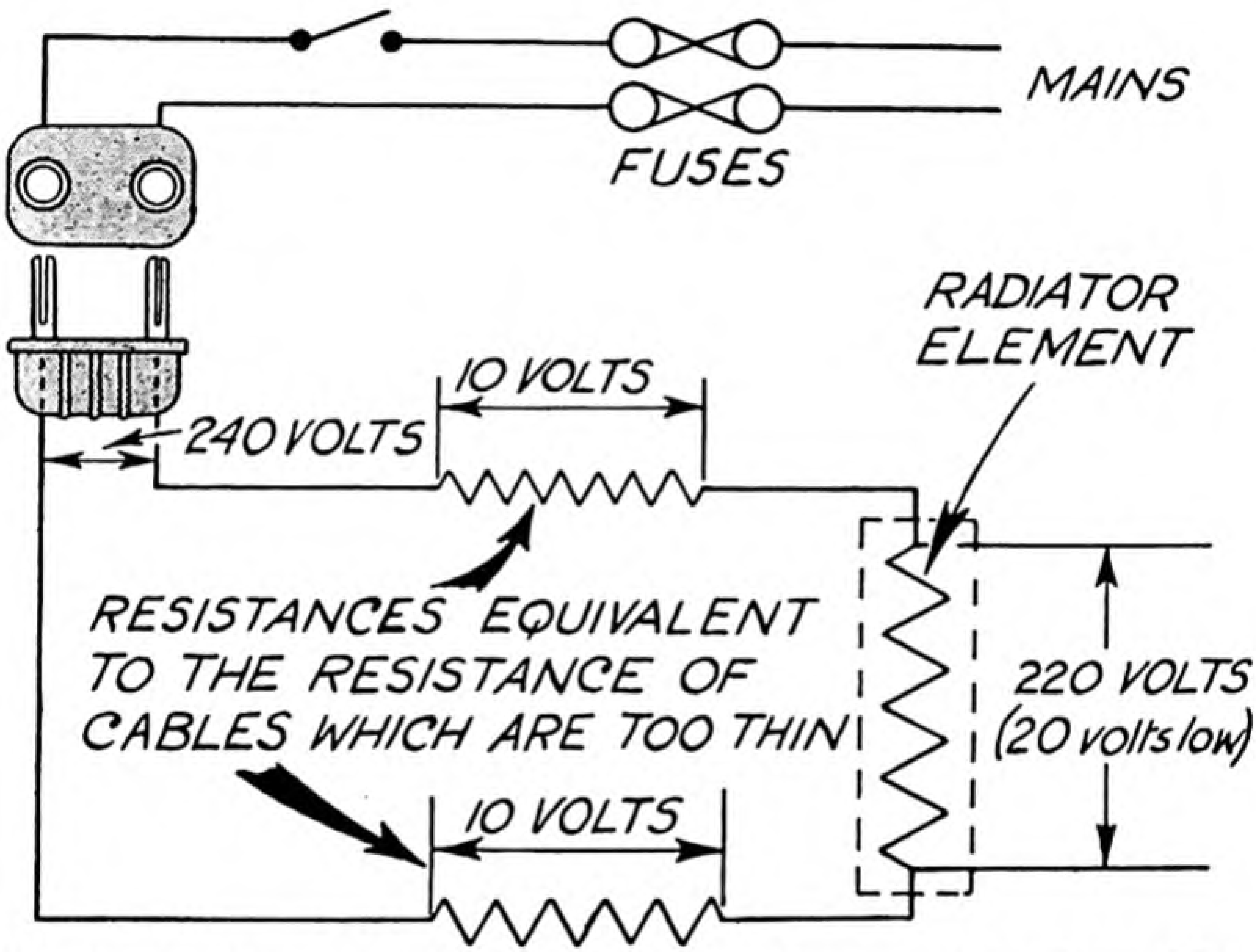


Fig. V, 6.—Diagram showing the effect of using connecting cables which are too small in current-carrying capacity

rubber or plastic covering, or else the conductor will melt, and thus draw an arc which may cause a fire. In any case, even if the wire gets only warm, the insulated covering will deteriorate and will eventually fail, thus possibly causing a fire by reason of a short circuit between the two mains connections.

For these reasons, it is extremely important to ensure that only the right sizes of conductors are used for bringing the energy from the mains to the appliance concerned. In the case of a portable generating equipment such as that used on motor vehicles and boats, it is necessary to make certain that the voltage drop in the wiring between the

generator and the battery, and the battery and the lights, is not too great.

Most types of flexible wire for domestic and industrial use are insulated for a normal voltage between poles of 660 volts; and therefore there is ample margin when they are used for 240-volt a.c. or d.c. circuits, and 415-volt three-phase motor circuits. This, of course, applies only to the voltage, and the size (the cross section) of conductor must be proportioned to the load also.

How are we to find what size of conductor to use for a given load? The apparatus will have on it some indication of its rating, which usually takes the form of a wattage figure; for example, an ordinary lamp might be marked "60 W". It will be recalled that watts equal volts times amperes. We are anxious to find the current, in amperes, which a 60-watt lamp will require:

$$60 \text{ (watts)} = 240 \text{ (volts)} \times \text{I (amps)}$$

$$\text{I} = \frac{60}{240} = \tfrac{1}{4} \text{ ampere}$$

so that the current will be one-quarter of an ampere. As another example—a bathroom water heater is marked "3 kW", which means 3,000 watts. How much current will this take from a 240-volt circuit?

$$3{,}000 \text{ w} = 240 \text{ volts} \times \text{I amperes}$$
$$\text{I} = 12{\cdot}5 \text{ amperes}$$

Some apparatus may be marked in ohms. In this case we can calculate the current directly and simply if the apparatus is used with direct current, or if it is of such a type that it has little inductance or capacitance. We apply Ohm's Law, and if, for example, the equipment is marked 120 ohms, then I (amperes) $= \dfrac{240 \text{ (volts)}}{120 \text{ (ohms)}} = 2$ amperes.

If the equipment is of an inductive nature, and is to be used on a.c. circuits, then the calculation becomes rather more involved. There is, however, one very rough and ready but safe rule. If it is possible to measure the resistance of the circuit, by methods which will be indicated in the next chapter, and if this is now taken as the guiding figure in calculating the current, one will be on the safe side since the a.c. "resistance", or impedance, will be greater than the d.c. resistance, and therefore less current will flow when the apparatus is operated on a.c.

Supplies to Motors

Another class of equipment includes all types of motors. Here the current may be marked on the motor name-plate, or a horsepower figure may be given. If the current is marked, there is no difficulty in choosing the right type of wire to use, except that allowance must be made for a motor taking a larger current at starting than when running. This current may be four or five times the normal current but will only persist for a few moments and thus will not have time to heat up the connecting wires to any great extent.

If the motor is marked in horsepower, we must then introduce a new calculation to indicate the relation between horsepower and wattage.

There is an exact relationship between mechanical energy and electrical energy, and this has been found to be that 746 watts equals 1 horsepower. This figure is the theoretically exact relationship, but in practice a motor cannot transform into mechanical energy the whole of the electrical energy fed into its terminals. This loss of efficiency is due to the following factors: the current needed to excite the field windings or the rotor (of a squirrel-cage motor); the heat generated in the copper windings and the magnetic losses in the iron of the stator and the rotor; the windage due to the fan-like effect of revolving the rotor rapidly in an airstream (and possibly increased by the provision of a fan on the end of the shaft for cooling); and also the bearing friction. All these losses add up to about 10 to 15 per cent of the electrical input in the case of large motors, and in the case of small motors of under one horsepower, may reach a much higher figure.

Thus, in converting the nominal horsepower figure on the motor name-plate to an electrical wattage, a liberal allowance must be made for this loss of efficiency; and it would not be inappropriate as a rough and ready guide, to add 50 per cent to the horsepower, and then to convert to watts by using the factor of 746.

Wiring Systems

Copper is the metal most widely used for electrical wire, owing to its high conductivity, its ductility, its resistance to corrosion, and the ease with which it may be soldered. Aluminium is nowadays used for an increasing proportion of power cable work.

The types of wire most commonly used in domestic and industrial installations are:

(*a*) Single conductors insulated with vulcanized indiarubber and

braided with a waxed cotton outer covering. The common term for such wires is "V.I.R.", and they are made in a large range of sizes, the smallest comprising only a single strand of tinned copper conductor, while all others have three or more strands, twisted together. A common description for such a conductor would be "7/·029". This means that seven strands of conductor are used, each with a cross-sectional area of 0·029 sq. in., this size being suitable for a normal full load current of 15 amperes, under suitable conditions, as specified in the appropriate Regulations.

This type of wire is normally used in a protective piping or casing, as will be seen later.

(*b*) Tough rubber-covered wire, where two or more conductors are first insulated separately by the use of vulcanized indiarubber and instead of each wire being covered with a hard rubber outer skin and a braid, as in the case of V.I.R., the conductors are together encased in a flat or tubular outer sheath of hard rubber. This is the well-known "cab-tyre" wiring system.

(*c*) The lead-covered wiring system, where the vulcanized indiarubber insulated wires are encased in a flat sheath, which forms a protective outer covering.

(*d*) A system which is increasingly used in industrial installations and sometimes for domestic wiring is the mineral insulated system, where two or more single strands of copper are embedded in a white powder-like mineral insulator, usually of a magnesium dioxide, enclosed in an outer copper sheath which of course does not carry current. In this way a considerable saving in size can be accomplished, and the cable is not subject to danger of fire as it is completely non-inflammable.

(*e*) For the largest power circuits paper-insulated lead-covered cables are used and this design is employed for the very high voltage cables, operating at pressures up to 380,000 volts. The conductor itself, which is of stranded tinned copper, although aluminium may be used, is taped with many layers of thin paper tapes, and the 3, 4, or more conductors of which the cable is made up are then brought to the circular shape by the addition of jute packings. A lead sheath is then tightly extruded round the whole cable, and a resinous oil is used to fill in the spaces between the paper tapes and between the conductors and the outer sheath. The purpose of using a paper insulator is that this material, when impregnated with resin oil, has a greater insulating value and a better degree of uniformity than rubber, and also has the advantage that gaps and spaces in the insulation which might be caused when the cable is bent round a small radius are immediately filled by the oil.

Although not used in permanent installations, the flexible cords employed for hanging lamps, vacuum cleaners, and the like, find a very wide field of application. The electrical engineer would always prefer if possible not to use a flexible cord, since it is liable to be damaged far more frequently than a permanently installed conductor. For very light circuits, such as single lamps, clocks, and radio sets, plastic-covered flexibles are suitable, and are made in varying sizes, some being very small indeed. Care must be taken to ensure that when a very light plastic flexible has been installed for one particular purpose and, at a later date, other apparatus is added, the capacity is not exceeded.

From the ideal electrical point of view, all wiring should be permanently encased out of harm's way. This is obviously not always possible, but complete protection should always be the aim of people installing electrical circuits. At this point another important consideration may be mentioned—that of providing an efficient earth connection at all outlets so that all equipment used can have its frame and outer casing properly earthed. It is highly preferable that the earth connection should be carried through with the wiring.

The best—and the most expensive—method of protecting wiring is to use galvanized steel conduit piping, which is screwed at all joints, with the proper elbows and connecting boxes always being employed. In this way complete metallic earth continuity is secured all the way from the mains to every single outlet. The V.I.R. wires are drawn into this conduit, care always being taken to ensure that no sharp edges are left, where the piping has been cut, to damage the wire. Red wire is used for the phase connection and black wire for the neutral. Various colour codes are used where the three-phase wires are all brought to an outlet point, the most common being red, yellow and blue for the three phases, and black for the neutral.

Next, in order of preference, to this system is a modification of it whereby a less expensive type of steel pipe is used, with clamp-type joints in place of screwed joints, resulting in a consequent saving in labour charges.

The lead-covered cable has the advantage of providing a metallic path throughout, and of affording some measure of protection to the conductors; but obviously a nail driven into a plaster wall would easily penetrate a lead-covered cable. It is desirable to use special oval-shaped protecting pieces, made in the form of pipes opened up, which can be slipped round lead-covered cable when it has been placed in position, to give added protection at any points where there is danger of subsequent mechanical damage.

The mineral insulated wiring system has many advantages, but tends to be expensive. It *must* be used where there is danger of the installation being subjected to considerable heat, since under these circumstances the rubber insulation of V.I.R. or cab-tyre would either melt outright, or become so brittle that it would crumble away.

The cab-tyre wiring system can be used with complete satisfaction if several precautions are taken. The best type of wire to use is that in which there has been included within the sheath a bare copper earth wire, as well as the insulated conductors, to bring the earth continuity connection right through to every outlet. Proper connection boxes must always be used, where correctly designed terminals are employed to join wires together. On no account should the wire ends be bared, twisted together and insulated with the sticky black tape known as "insulating tape", as such joints are never reliable.

When cab-tyre wiring is used it can be buried in plaster, but again there is need for a metallic protecting sheath, and in view of its vulnerability, it should either be run along a route where it is completely immune from mechanical damage, or else protected in some suitable way. Where it has to be brought across a surface where there is a possibility of damage, failing all else it is better to leave it bare and apparent so that persons are aware of its presence and may take care to avoid it. Direct sunlight is liable to cause a deterioration in rubber sheathing if the cable is subjected to its effects permanently, and this point should be taken into account when designing the wiring run.

Wiring of Premises

For wiring a factory, there is little possibility that any other type of wiring than steel conduit, in one or other of its forms, would be found acceptable by the insurance authorities. In domestic premises, where a new installation is being fitted, again V.I.R. in conduit is the best type of wiring to install. The difficulty arises, however, that extensions to this system, with the need for running inflexible pipes along an awkward route, may sometimes involve a great deal of breaking away of plastered walls and the like, with the need for a considerable outlay when making good. Thus there is a case for using the much more flexible lead-covered wiring system, or cab-tyre wiring, but great care must be taken when changing from one system to the other to use the proper types of adapter. Fittings are available whereby a gland, which can be screwed in to the steel conduit system at a suitable junction box, takes the lead-covered or cab-tyre cable and

clamps it securely. The lead sheath is thus in mechanical connection with the continuous earth provided by the steel conduit, and if cab-tyre wire is used the earth wire must be properly secured to the metallic body of the junction box where the change-over is made.

If wiring has to be carried out of one building into another, special precautions must be taken. The most satisfactory method from the electrical point of view is to use a cable, and if the load is considerable, a three-phase paper-insulated lead-covered cable, with steel wire armouring to prevent external damage, will be employed. This cable must itself be protected by having special bricks or concrete slabs placed above it, with a thin layer of stone-free soil in between, or it may be laid in earthenware ducts. Such a cable should be sealed off at each end by means of a plumbed joint into a proper sealing gland, filled up with bitumen compound, so that no moisture can get in. It is not desirable to lay V.I.R. in conduit underground, as the conduit will eventually corrode, and in any case condensed moisture will accumulate inside and the cable will be lying in a pool of water.

If the wiring is to be taken overhead, the wires themselves should not be allowed to carry their own weight. The ideal method is to use a galvanized steel messenger wire slung across the route and tensioned up so as to be approximately horizontal, and then the V.I.R. wiring may be suspended from it in slings made up of leather thongs (but not of wire which would cut into the cable), and led through the walls of buildings through earthenware ducts with smooth edges to prevent abrasion. If the length of outdoor run is considerable, bare wire supported on insulators may be used, as in distribution systems in rural areas, or wires with a special kind of insulation may be employed, this taking the form of a flexible bitumen compound. In this latter case the wires may be situated more closely together, as there is no danger of flashing and short circuiting occurring if they are made to touch by the wind.

It is inadvisable to embark on overhead line construction without a careful study of all the many Rules and Regulations which bear on this type of work, since severe legal liabilities may be incurred if an accident happens through the breaking of a wire, or the contact of objects such as ladders being carried along the ground in an upright position takes place with an unprotected overhead line.

In examining the various parts of an electric circuit from the generator to the point of utilization, we come first to the mains connection, where there will be a switch, a fuse for the whole installation, known as the main fuse, a meter, and a sub-fuse board with smaller fuses for the individual circuits.

Switches

After this main "intake point", there comes the wiring, and then the various sub-distribution boards and the switching points where control of the various circuits is achieved.

The simplest form of switch is the plain knife switch. The name arises from the similarity of this switch to an ordinary table-knife, with its bone handle acting as the insulator, the blade being pivoted on a hinge at the tip, and closing into spring-loaded fixed contacts to complete the circuit. Such switches are still widely used, but whereas in the early days of electrical engineering they were bare and unprotected, nowadays they nearly always operate inside an enclosure, and several modifications have been introduced as a result of experience. First, the hinge itself is seldom used to carry current, owing to the difficulty of keeping the mechanical joint tight to secure good contact, and at the same time free for ease of operation. This means that switches either have a flexible connection bypassing the hinge, or else are so arranged that there are two knife switches operated together, which short circuit the two fixed contacts without the need for current flowing in the hinge.

In the early days of controlling electrical circuits, it was soon found that the main hazard to the operator lay in defective methods of switching. When interrupting any electrical circuit, there is always the danger of drawing an arc which may give rise to fire or explosion.

Arcing

The mechanism of the formation of an arc is worthy of brief study. Imagine an electric circuit in which a considerable current was flowing, and which included two metal bars pressed together. If one of the bars could be moved away from the other by a very small amount, the full voltage of the circuit would appear across the break. This would mean a very severe stress on the dielectric (in this case, air), between the two bars, and ionization would take place. The electrical stress across this very thin layer would cause electrons to fly off from the atoms of which the air was composed, and once an electron stream had started, the air would become conducting. The intense local increase in electron activity would cause heat to appear, resulting in the familiar spark. If the two bars were now slowly drawn farther apart the arc would stretch and become more powerful, until the cooling effect of the atmosphere, or some chance atmospheric disturbance, blew away the stream of ionized air and restored the

insulation strength of the gap by substituting pure air, which is not a conductor.

The first lesson learnt by the early electrical engineers was that the knife switch must not be opened slowly and for this purpose they added a small auxiliary blade, coupled to the main blade by a spring, so that whatever the operator did by way of moving the main blade slowly, the auxiliary blade stayed closed until the spring was fully extended, when it snapped open, resulting in a "quick break" (Fig. V, 7).

In the case of direct current the arc will strike and will continue until the separation of the contacts, or some external influence, causes it to be extinguished; but with alternating current, the arc is actually extinguished at every current zero, that is, 100 times a second on a

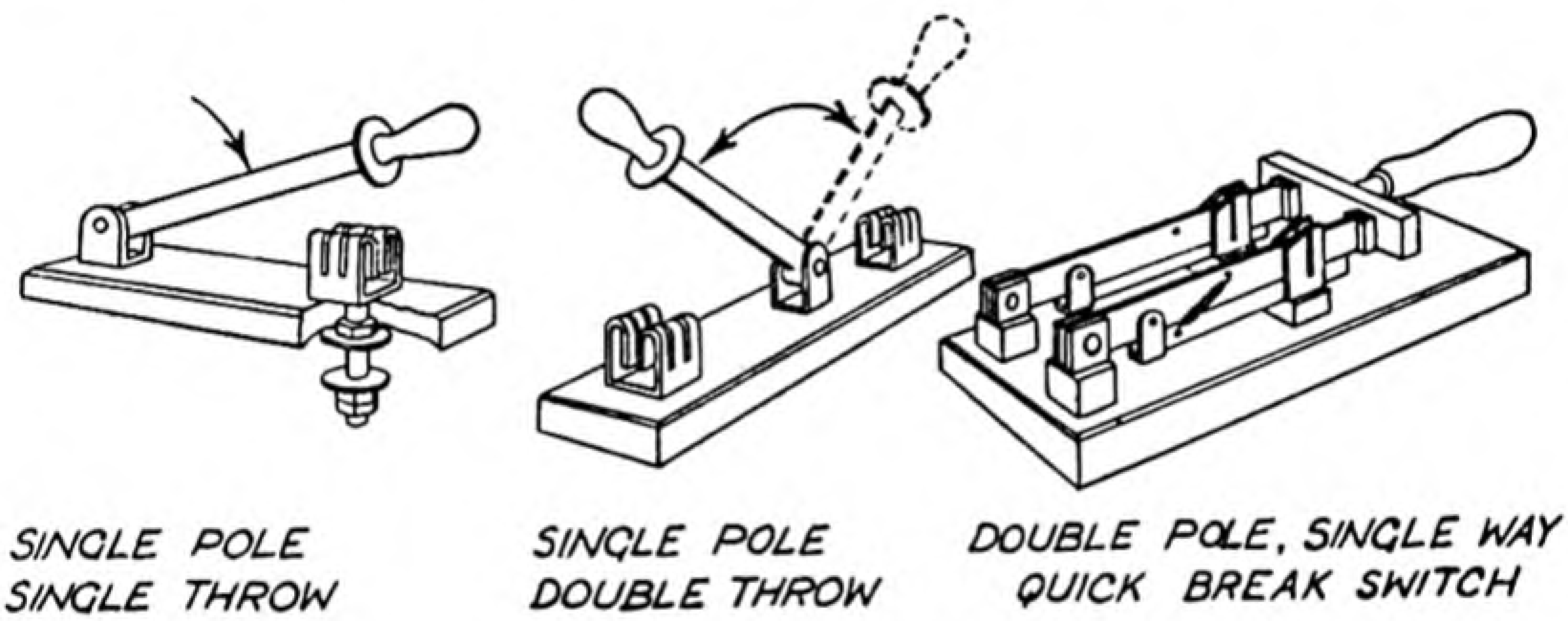


Fig. V, 7.—The knife switch

normal 50 c/s system. The heat inertia of molten particles of metal on the two contacts is likely to cause it to restrike again when the voltage rises to its maximum value in each half wave.

Large arcs on power systems are always extinguished in circuit breakers (the name given to large switches) by taking advantage of this zero extinguishing feature. Large d.c. arcs are difficult to extinguish, and the method generally used is to employ a magnetic coil to deflect the arc, which can be treated like any other conductor and will therefore move when attracted by a magnet, so that it is lengthened and cooled until it breaks down. This type of device is known as a blow-out coil.

The Tumbler Switch

The ultimate development of this type of switch was the tumbler switch, which is perhaps the most widely used of all types of electrical

apparatus of any kind anywhere in the world. The tumbler switch, as used in domestic premises, incorporates a number of devices that have been developed for safety purposes and to ensure long life. The usual form consists of a bakelite or porcelain base, on which is mounted the switch assembly. Most tumbler switches are of the single-pole, double-break type, which means that one side only of the circuit is broken, but by two breaks in series. Special double-pole type switches are sometimes used, in which both sides of the circuit are interrupted.

There are many patented variations of the tumbler switch mechanism. A typical arrangement consists first of two thin bronze strips folded in such a way to form the fixed contacts, each attached to a tubular contact-post equipped with a securing screw for the bared end of the conductor. The moving arm is in the form of a fork, and when closed bridges the two fixed contacts. The fork is held on an insulated cradle, pivoted on the base, and a helical spring together with a toggle mechanism ensures that the dolly (the knob by which the finger operates the switch) has a "snap" action and cannot be operated slowly. No matter how slowly one attempts to move the knob of a properly designed tumbler switch, one will feel the tension of the spring increase, without any action taking place, and then the fork will snap open (Fig. V, 8).

For the main switches employed in factory and domestic premises, a knife-switch action enclosed in a metal or bakelite box is provided with a quick break action and also with an interlock so arranged that the cover cannot be opened with the switch in a closed position.

There are also devices known as switch-fuses, in which the moving blade assembly, which bridges the fixed contacts, is made up in such a way that the "blades" are in fact high rupturing capacity fuses, in cartridge form. In normal operation, the switch is opened by operating it by hand in the usual way; but if a fuse is blown, the operation of the switch automatically isolates the fuse-carriers, and so makes it safe for the operator to renew the blown fuse cartridge.

In corrosive or inflammable atmospheres, special types of switch are necessary. For flame-proof switches, the casings are made of very strong metal, and the switch is completely sealed so that inflammable gases cannot enter. The casing is so designed that it can resist the effect of an explosion *inside* the switch, if the small quantity of inflammable gas within the enclosure is ignited by a spark drawn when the contacts separate.

Other types of switching appliance for small power circuits include microgap, vacuum and mercury switches.

Microgap switches are tumbler switches designed for a.c. circuits

only, and they take advantage of the fact that the arc is extinguished at every zero point to utilize a very small mechanism so that the switch can be made quieter and of much reduced overall dimensions.

If the arc could take place in a vacuum there would be no burning of the contacts as there would be no oxygen present to support combustion. This principle is used in special switches for controlling certain

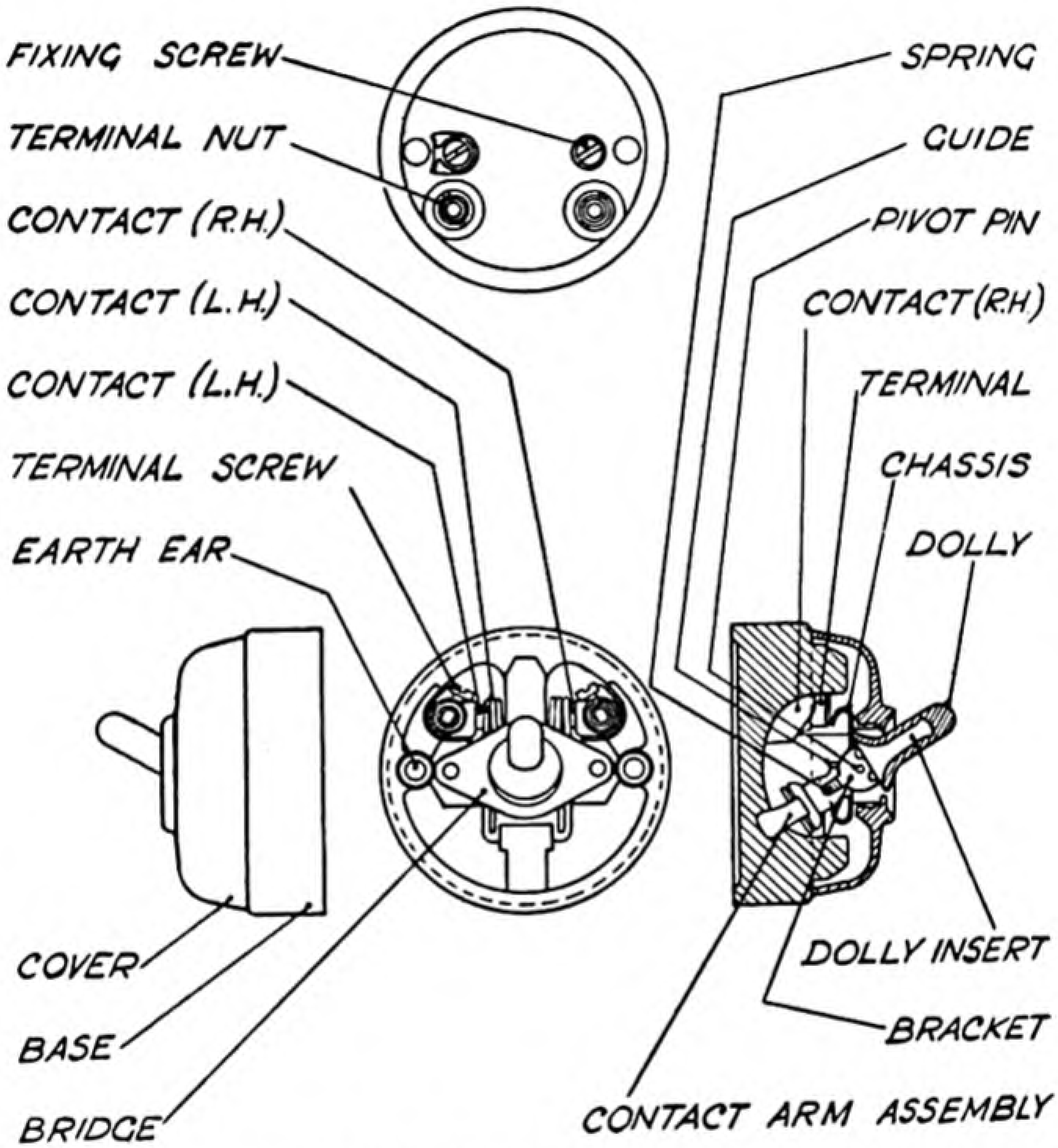
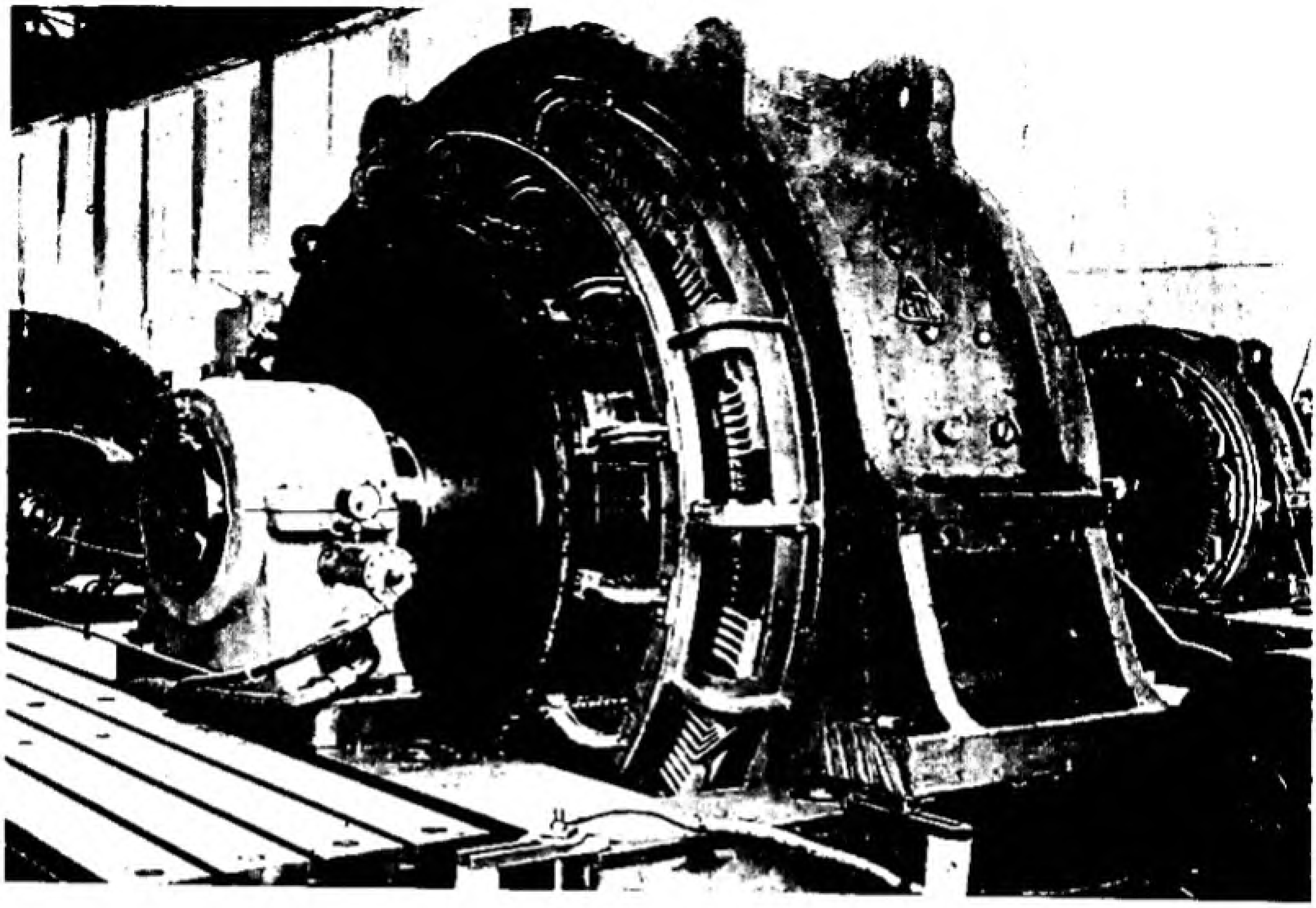


Fig. V, 8.—A typical design of tumbler switch (Lundberg)

appliances, the contacts being enclosed in a glass tube and being made up of bi-metal strips, which bend under the influence of heat. Incorporated in the tube is a small heating element, supplied from an auxiliary circuit. When this circuit is energized the heat causes the bi-metal strips to bend and to make contact. When the heat is switched off the contacts spring apart and break the circuit.

Another type of switching device, the mercury switch, again employs the vacuum principle (Fig. V, 9). A glass tube has two electrodes fixed through the glass, usually fairly close together at one

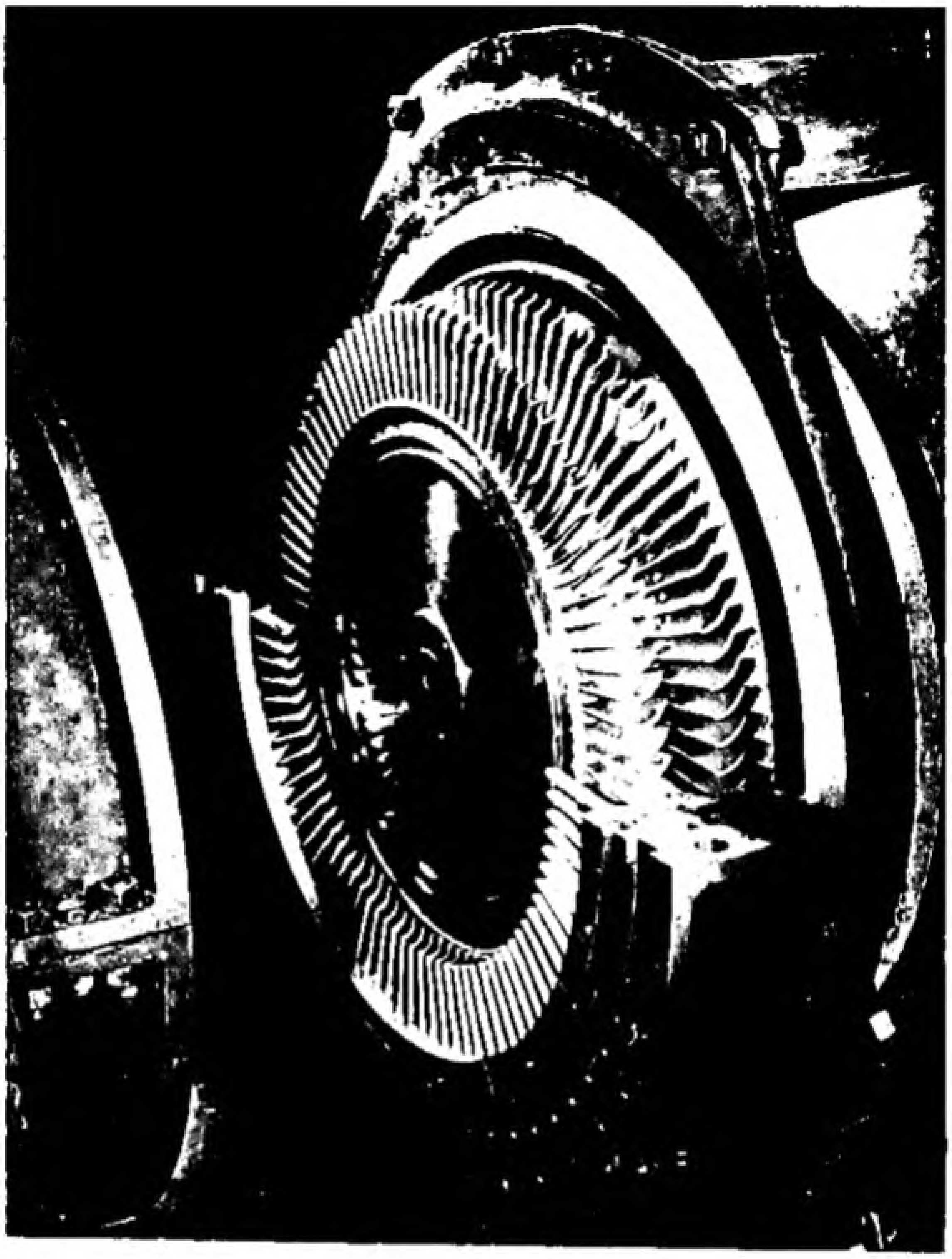


Elin, Vienna

PLATE 1. A 12,000 h.p. direct current motor for driving a steel rolling mill

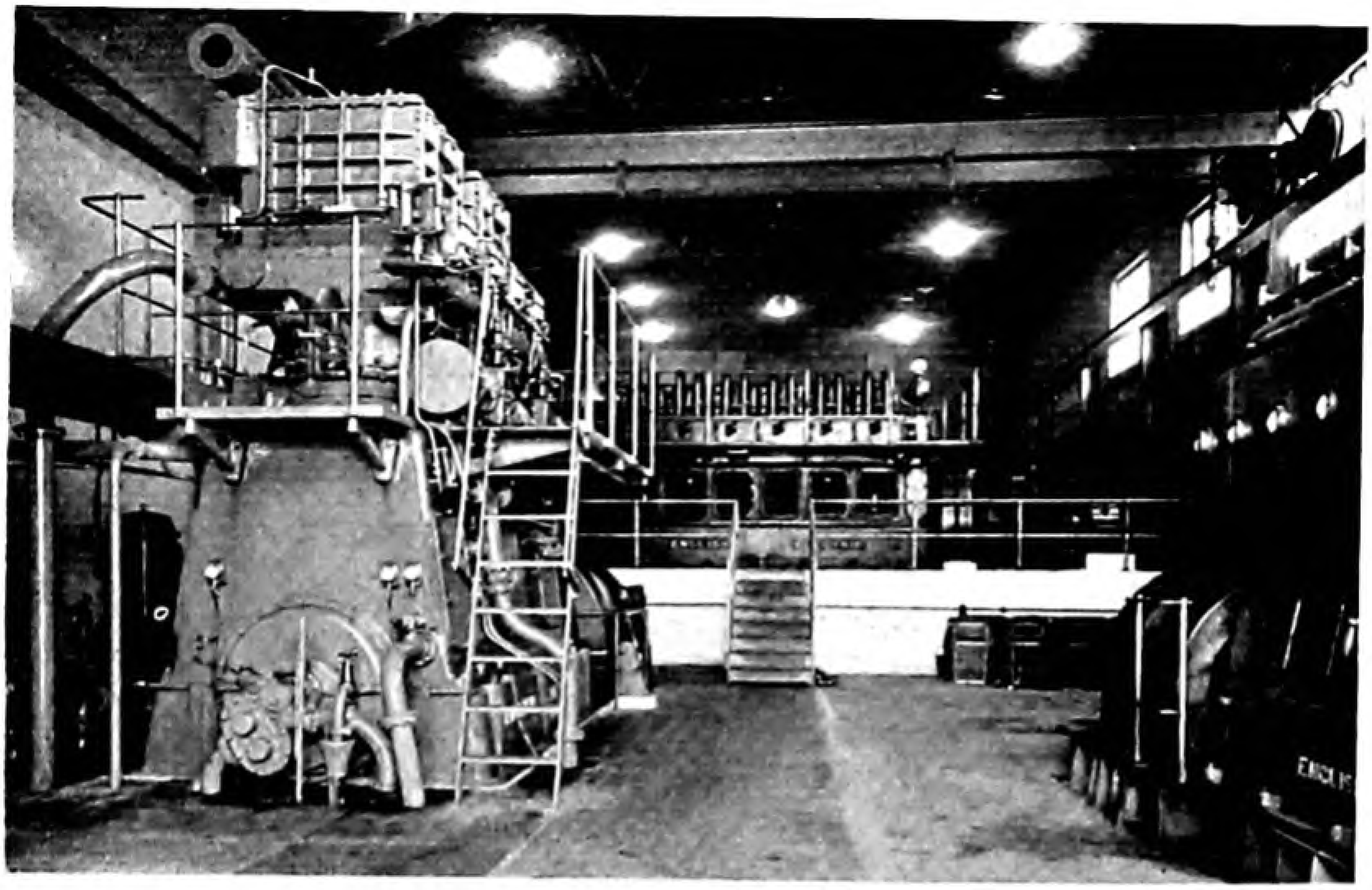
Ruston & Hornsby

PLATE 2. A 1,000 kW gas turbine: the compressor rotor, showing the blade rings



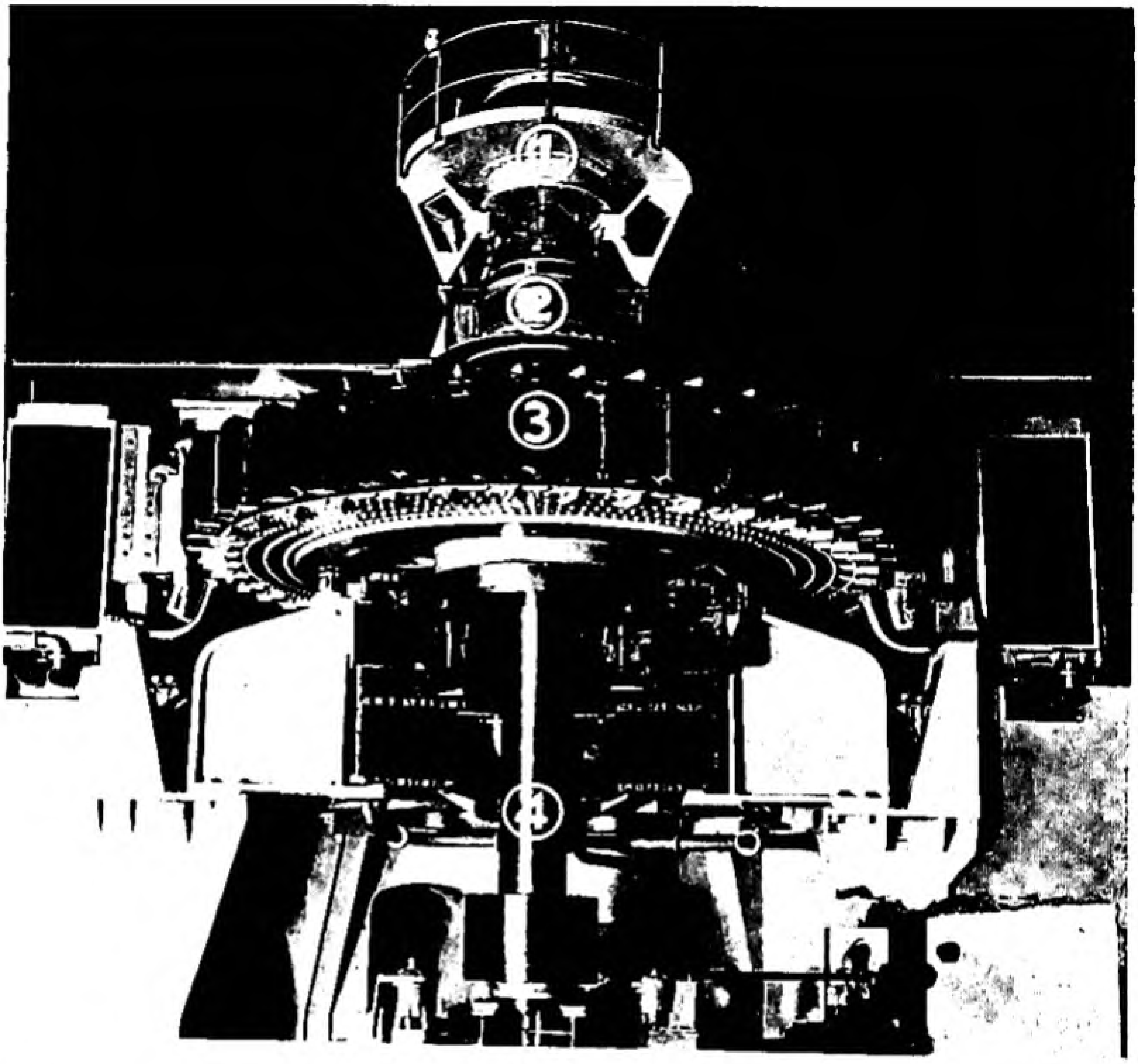
Ruston & Hornsby

PLATE 3. The turbine blading of a 1,000 kW gas turbine



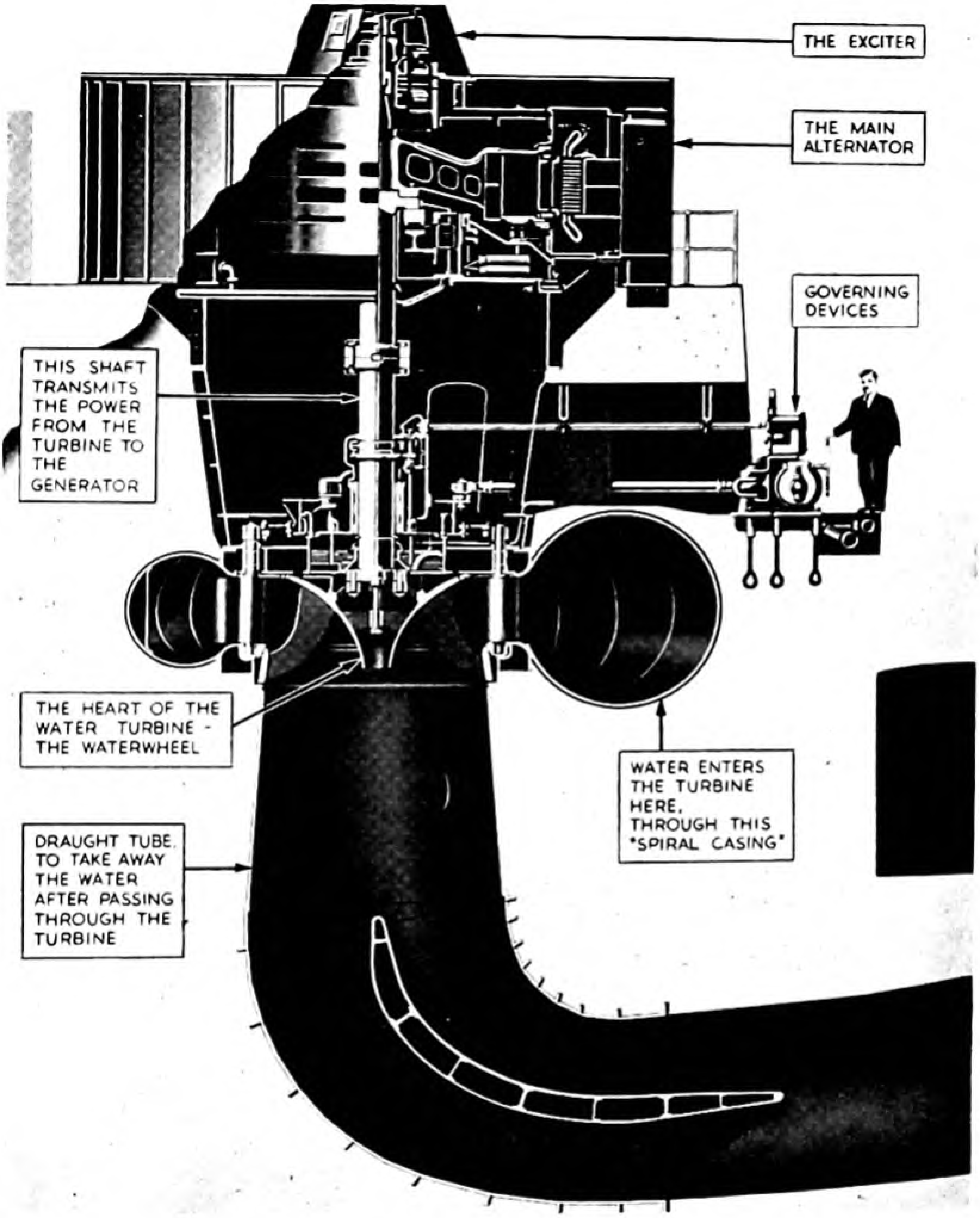
Central Electricity Authority

PLATE 4. A diesel engined-power station



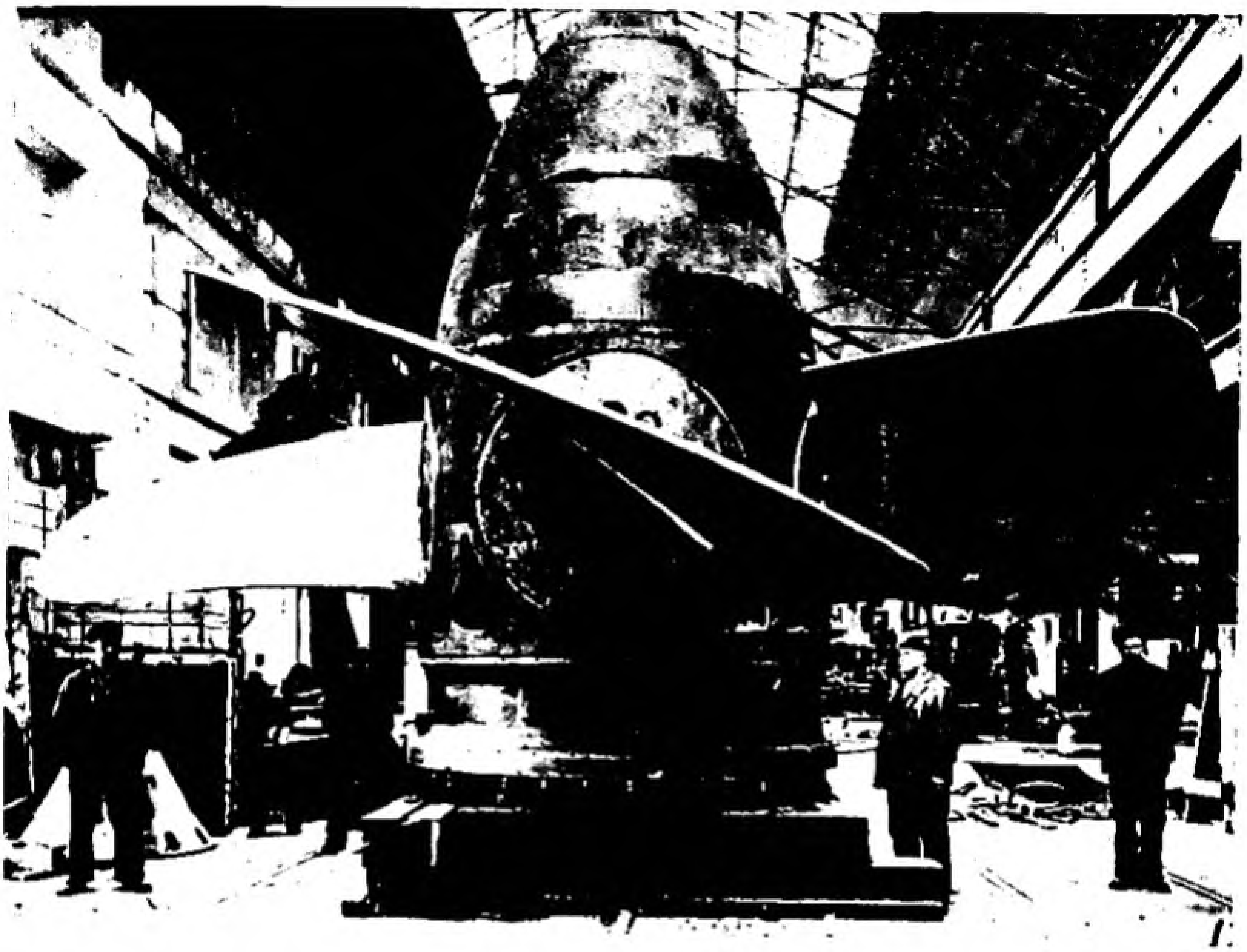
English Electric

PLATE 5. A model vertical hydro-electric generator. (1) The top bearing; (2) the exciter, for providing the direct current to excite the rotating magnet coils of the field winding, seen at (3); (4) the shaft carrying the drive from the turbine below



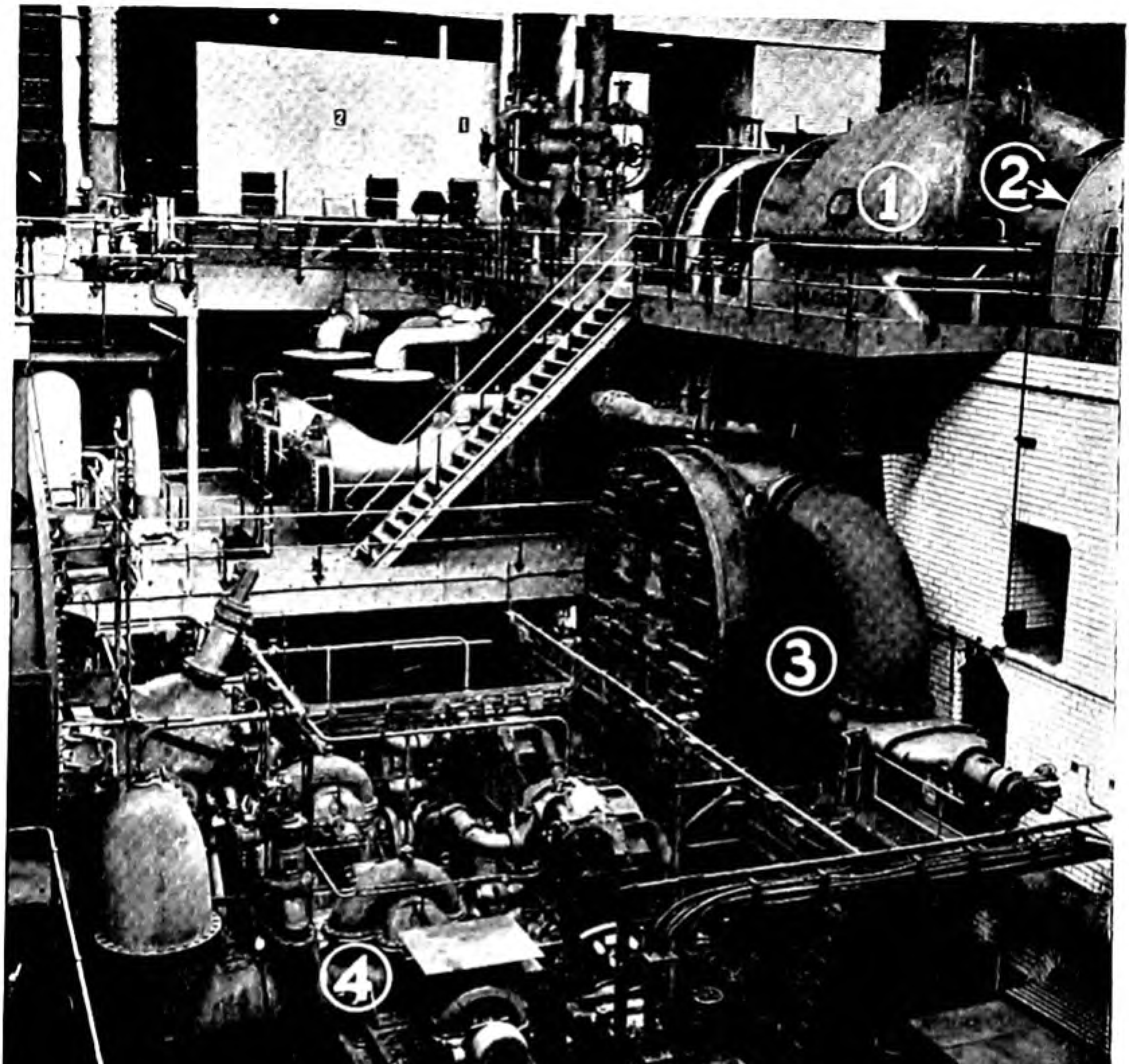
English Electric

PLATE 6. A vertical Francis water turbine



A.S.E.A.

PLATE 7. A large Kaplan waterwheel, showing the method employed for adjusting the pitch of the blades



Central Electricity Authority

PLATE 8. The layout of the plant associated with a steam turbo-alternator. (1) The turbine; (2) the alternator; (3) the condenser; (4) the auxiliary equipment, including feed pumps, vacuum pumps, etc.

end, and when a small quantity of mercury has been introduced the tube is exhausted of air. The mercury switch is held by a clamp which is pivoted so that the glass tube can be tipped either way. When the switch is tipped in one direction, the mercury runs to that end and bridges the two contacts. When the switch is turned the other way, it runs away from the contacts and breaks the circuit. Such switches have the great advantage that there is no wear and tear on the contacts, and arcing is negligible when the switch is used within its rated capacity.

Various types of special control circuits can be provided by the aid of tumbler switches with the required connection arrangements. The first and simplest special circuit is the two-way switch commonly

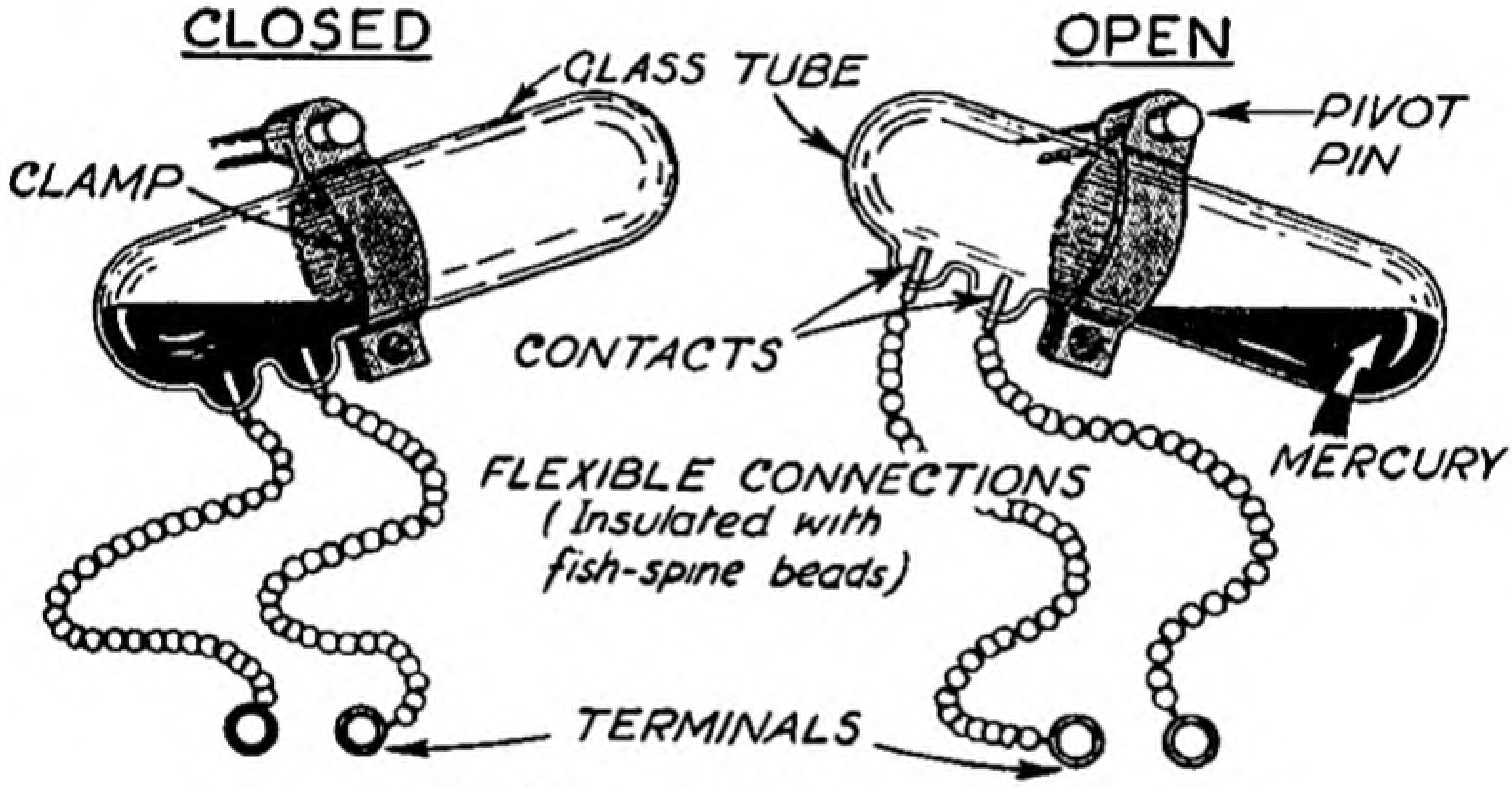


Fig. V, 9.—The mercury switch

used in domestic installations to switch on a light at the foot of the stairs and then to switch it off again from the top (Fig. V, 10). This is achieved by the circuit indicated in the figure. Two tumbler switches are used, each equipped with a change-over action so that the current flows either from the common point to the "top" contact, or to the "bottom" contact. The top contact on one switch is connected to the top contact on the other, and the bottom contacts are likewise connected together. This circuit is then inserted in place of the normal single-pole switch. If both switches are on their top contacts, the circuit is made and the lamp will light. If the switch, say, at the top of the stairs, is then altered so that its blade is on the bottom contact, the circuit is broken. Anyone approaching the bottom of the stairs can then move his switch so that the blade is on the bottom contact and the circuit is once more made.

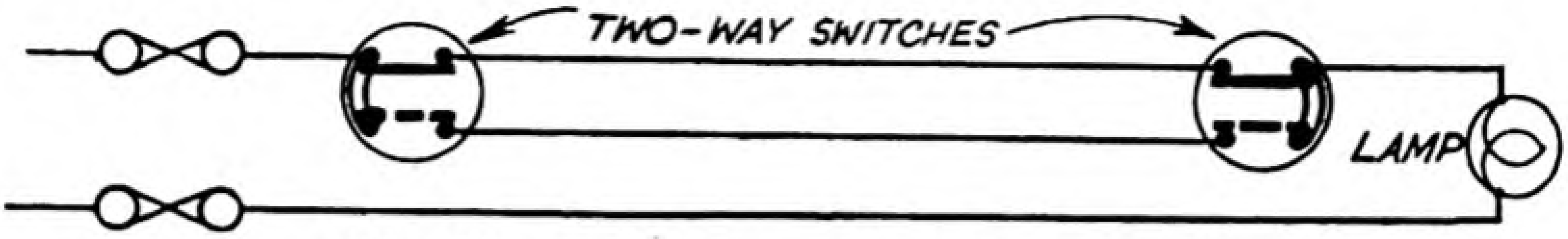


Fig. V, 10.—Two-way switching circuit

This change-over switching arrangement can be applied to give control from three or more places (Fig. V, 11). The two wires connecting the top and bottom contacts of the two two-way switches have only to be interchanged for the circuit to be made or broken as required. If a switch—known as an intermediate switch—is used in which this change-over can be carried out, the additional control point can be situated anywhere on the run of the two wires joining the two-way switches.

There are many other special switching circuits which can be arranged by the use of tumbler switches of various kinds. For example, a dimming circuit can be arranged with two ordinary lamps, normally connected in parallel so that both are bright, i.e. supplied at full voltage, which can be switched so that they are connected across the supply in series. If the lamps are of the same wattage, they will then each receive half the normal voltage and will both burn dimly. This type of circuit is sometimes used in hospitals and sick rooms. There are also master switch circuits, so that one switch can be used to turn *on* or *off* a given number of lights which cannot be turned *off* locally

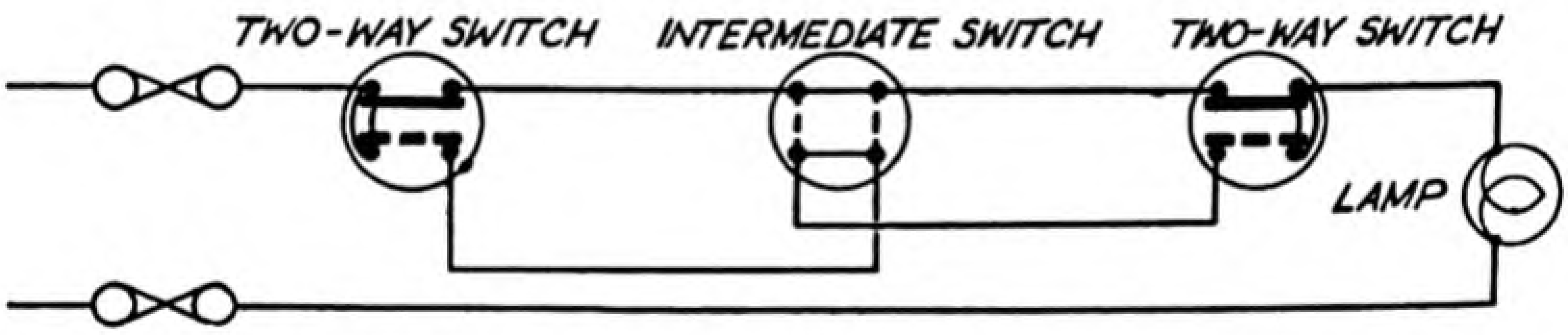


Fig. V, 11.—Three (or more) switching positions

(Fig. V, 12 and 13). This type of circuit is useful for hotel corridors and the like, so that no chance operation of a switch can plunge a corridor into darkness, on the one hand, and for saving current on the other.

High Power Switches

When voltages of the order of 6,000 volts, and currents of hundreds of amperes have to be controlled, the ordinary knife switch, operating in air, cannot be used, as it would be impossible to control the arc.

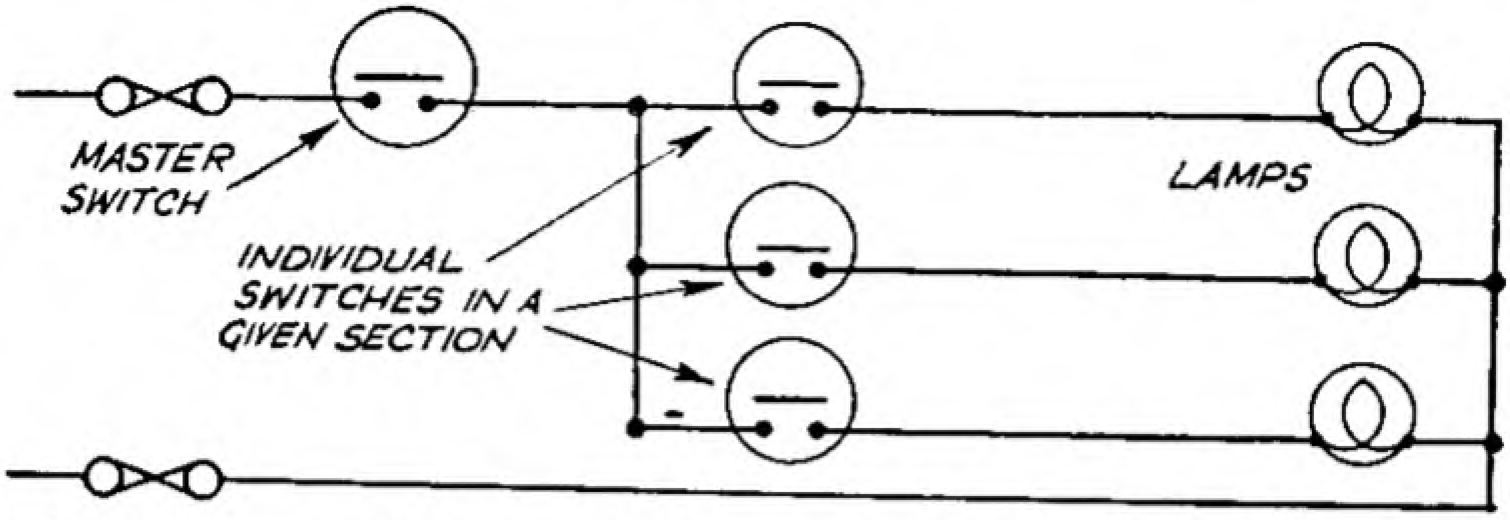


Fig. V, 12.—Master switch for switching *off* a number of lamps or circuits

Two basic methods are employed. The oldest, and one which is still widely used, is to immerse the circuit breaking mechanism in a tank of insulation oil. This has the effect of quenching the arc (Fig. V, 14). The second method is to employ an air-blast circuit breaker in which compressed air is used. A stream of high pressure air is directed across the arc, so that it is almost literally blown out (Fig. V, 15).

Either of these two designs of circuit breaker may be built in sizes large enough to deal with the highest voltages used anywhere—up to 380,000 volts (Plate 14). For these large circuit breakers a number of separate breaking units is installed in series in such a way that they open together, thus dividing the voltage between them. The large circuit breaker is naturally closed and opened by remote control mechanisms, as otherwise it would be dangerous or impossible for an operator to close or open the contacts. Springs, motors and solenoids are all used for this purpose.

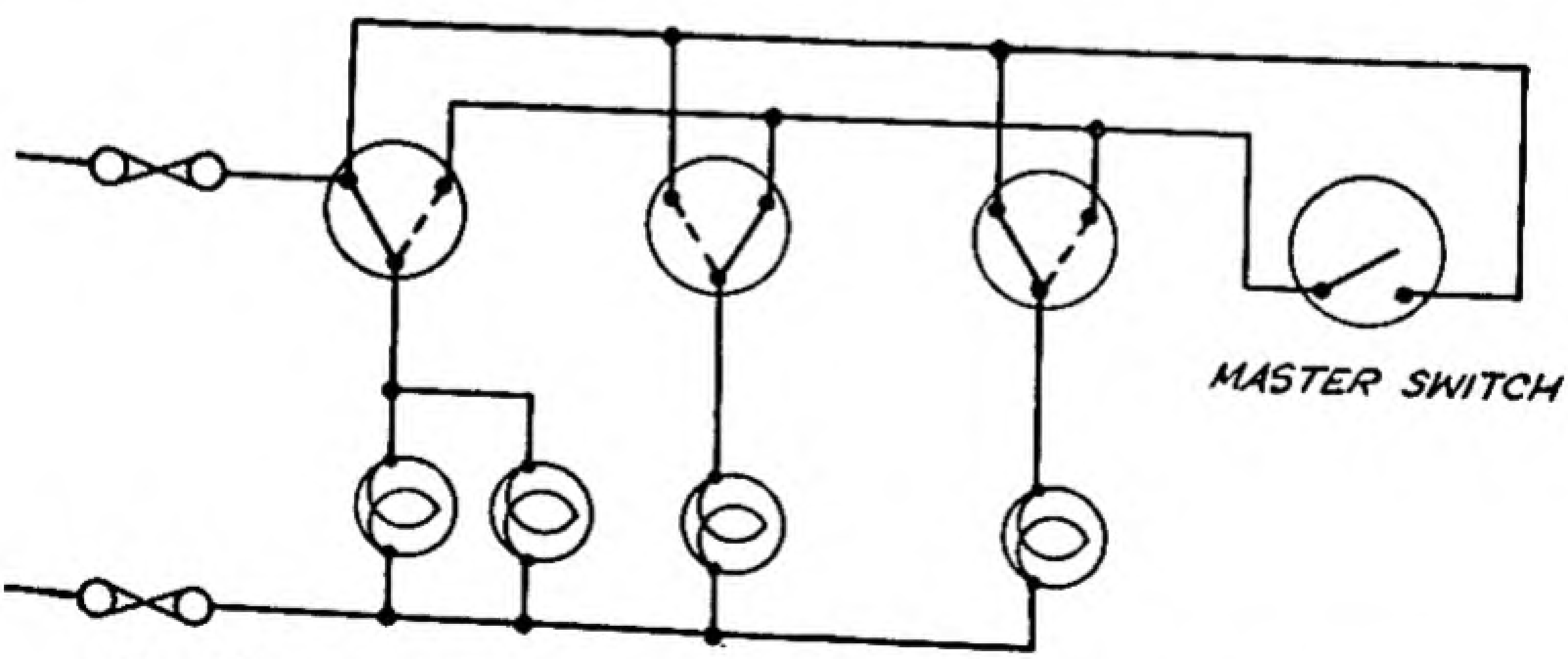


Fig. V, 13.—Master switch for switching *on* all the lamps

Relays

Another type of switching device for the control of electric circuits which is commonly used is the relay, and its more powerful brother the contactor. In both of these devices the basic principle is to use an

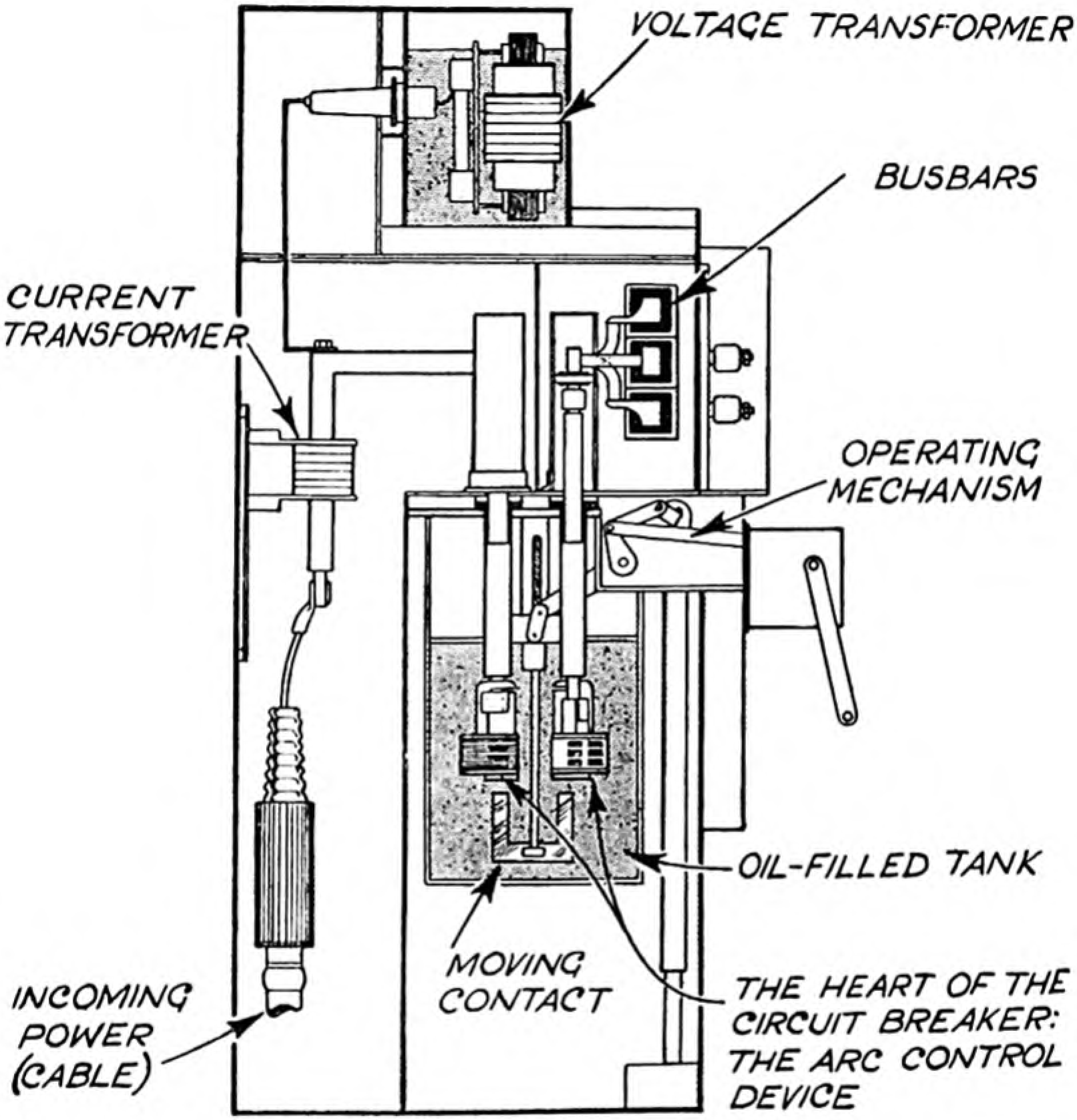


Fig. V, 14.—An oil circuit breaker

electromagnet attracting a moving armature which in turn causes the operation of secondary contacts (Fig. V, 16).

Relays are used to enable a light current device to operate a heavy current circuit. A typical example is the operation of a street lighting system by means of a "magic eye" or photoelectric cell, which takes account of the level of daylight at any particular time. This cell gives out a current which is measured in thousandths of an ampere, and may

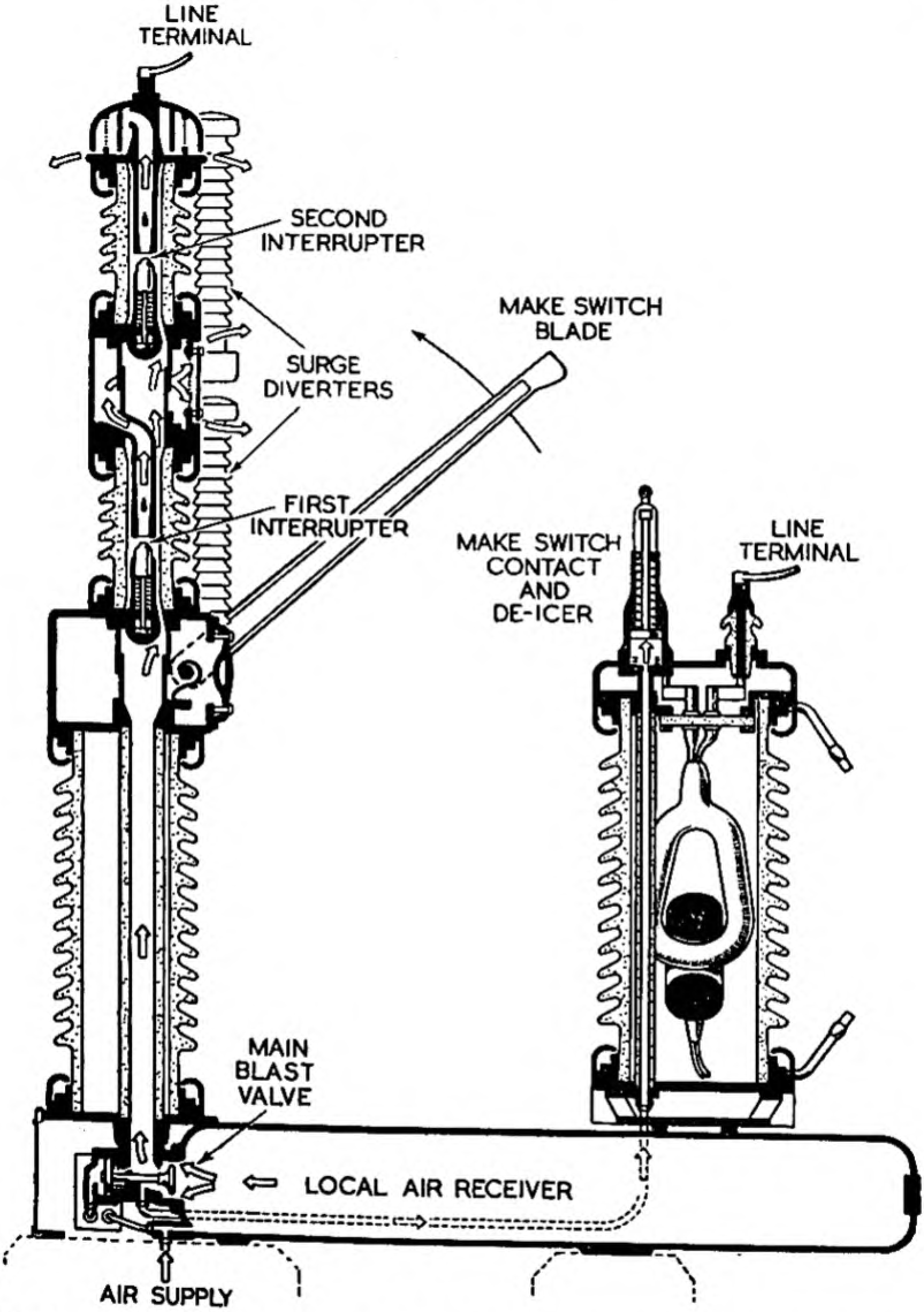


Fig. V, 15.—A typical design of air-blast circuit breaker (English Electric). When the switch opens, a blast of compressed air from the air receiver opens the interrupters, and the "make switch" then opens and isolates the circuit. Closing is effected simply by closing the make switch

have to control the operation of very large currents for the street lamps. The relay is a precision instrument, similar to a voltmeter or ammeter, and when the very small current from the photoelectric cell reaches a certain value, its coil picks up and it closes contacts which can handle perhaps 1 ampere. This circuit in turn closes the electromagnet coil circuit of a heavier relay, called a contactor, which can close a circuit in which perhaps 100 amperes can flow.

Relays are also employed for such purposes as burglar alarms and remote control of lighting, by using a low voltage circuit, which is perfectly safe to handle, and which involves only inexpensive wiring,

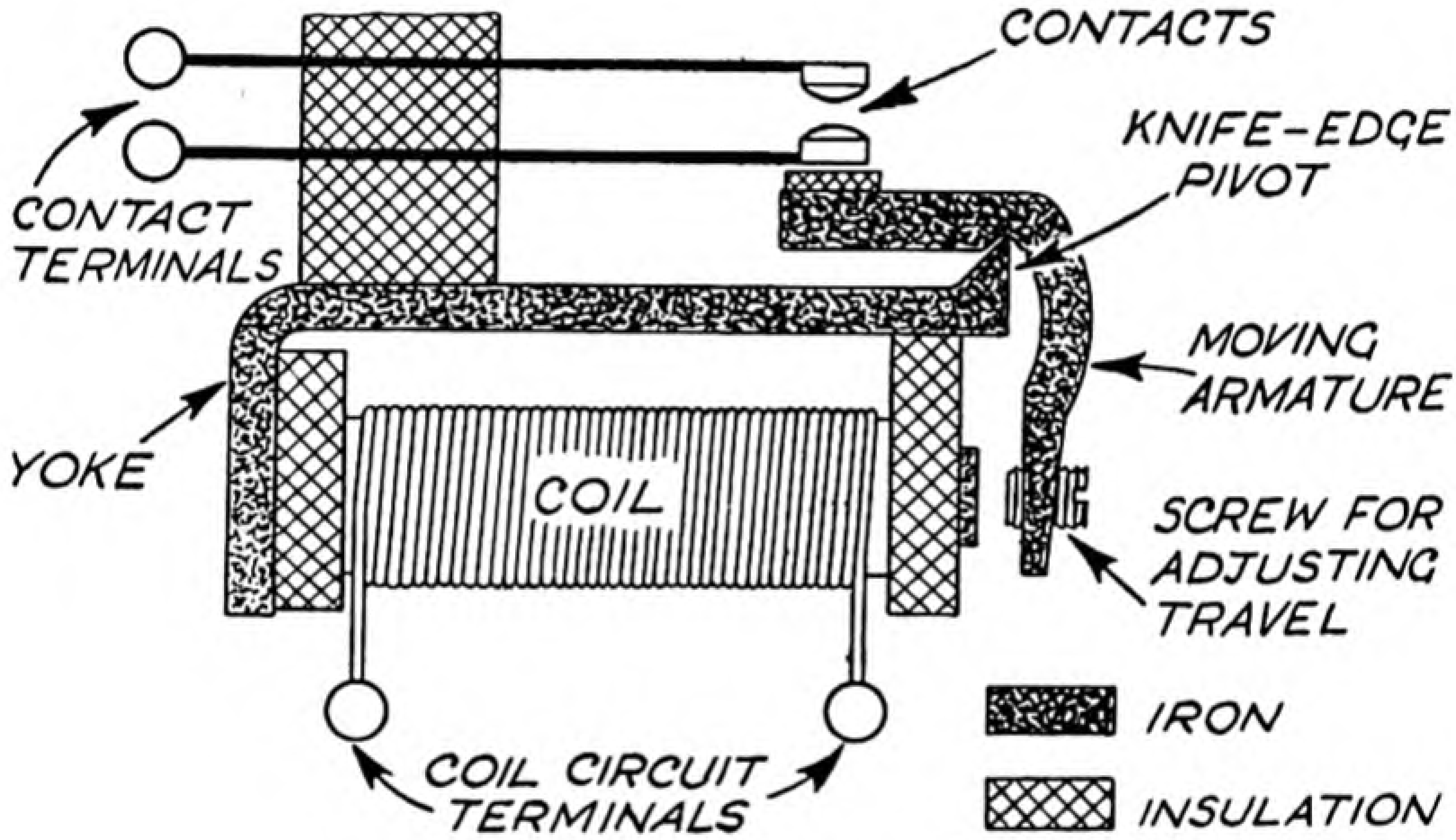


Fig. V, 16.—A typical relay

for operating a master high voltage control from a large number of points.

Contactors are widely used for starting electric motors. In fact, the larger types of motor *must* have some form of contactor starting, as hand-operated starters would be impracticable (Plate 15). Contactors are made in sizes so large that they become in effect circuit breakers, although the distinction is that they are not primarily meant for general circuit breaking duties, but only for a particular application.

Electrical circuits may also be controlled by electronic means and this method is being used more often. The usual method is to include in the circuit a thyratron or gas-filled triode valve, which has the property of being able to be "triggered off", to become conducting, by the application of a voltage impulse to its grid. To block the circuit,

the grid impulse is removed and the thyratron will become non-conducting at the next zero point in the current wave.

Dimming of lighting circuits is another form of electrical control and can be carried out in two ways. The most commonly used method is the resistance dimming system, in which resistance wire, wound on spirals and mounted on a suitable frame, is connected to a number of studs arranged usually in a circle. One end of the resistance is connected to one side of the circuit, and the other side of the circuit is

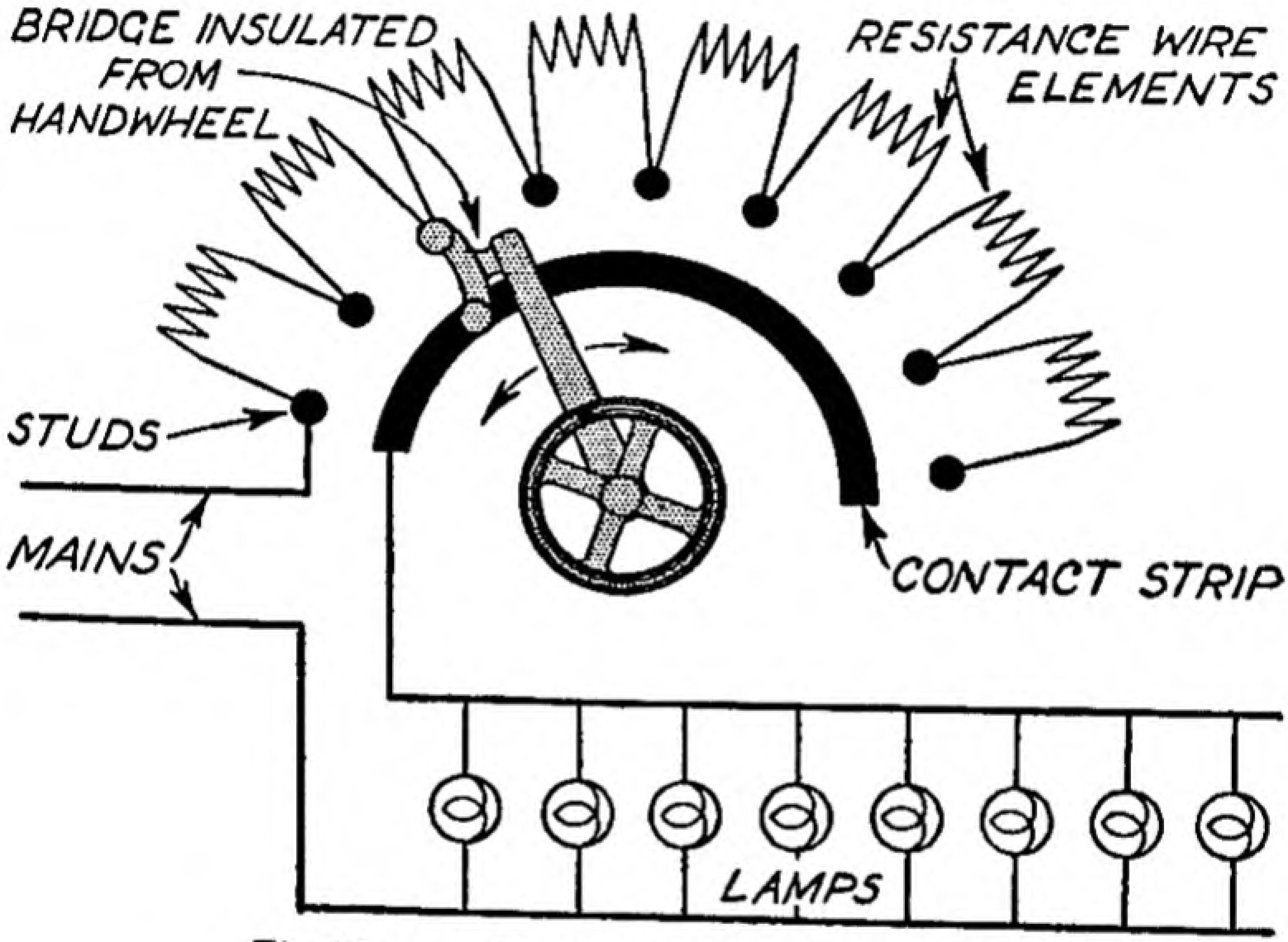


Fig. V, 17.—Resistance dimming circuit

connected to a moving arm, which can sweep round and make contact with any of the studs. As it moves round more resistance is introduced into the circuit, with a result that of the total voltage available, a greater proportion will be dropped across the resistance and less across the lamps. Progressive dimming is thus achieved (Fig. V, 17).

The second method is to use triode valves, where the current flow through the valve can be controlled by varying the voltage applied to the grid. A bank of valves of this type is connected so that it supplies the lamps to be dimmed, and a very small variable resistance, similar to that used, for example, as the volume control of a radio set, can then be employed to control the dimming, in a completely smooth and continuous fashion, of many hundreds of large lamps.

Protective Devices

The protective devices used in connection with electrical circuits take many forms, as circuits may have to be protected against over-current, over-voltage, reversal of power flow, disconnection of one of the phases of a three-phase supply, and other abnormal conditions.

The most commonly used form of protective device is the fuse. It can carry out one function only, that of protecting against over-current, but as many of the other abnormalities ultimately result in over-current in some part of the system, the fuse has a wide range of application. In an ordinary domestic installation, the fuse may be regarded as a "deliberate weak link", so that if an excess current occurs, the circuit may be interrupted at a specific point where the arc can be under control, and so cannot give rise to fires or explosions.

Basically, the fuse consists of a length of wire, sometimes of lead or tin or some suitable alloy, but more often of thin tinned copper wire, which will melt and so interrupt the circuit when a given degree of excess current is passing. The simplest form consists of a bridge of porcelain, or some other fire-proof material, with two contact clips between which the fuse wire is stretched. The wire is often enclosed in an asbestos tube, for greater safety against fire. The bridge is usually arranged to be inserted in a porcelain fuse body to which the terminals of the circuit are connected. In the majority of cases, fuses are provided on both sides of the circuit.

The normal fusing arrangement is to have a main fuse situated immediately after the incoming supply terminals, which is of a large enough capacity not to operate except in an emergency. Following this will be a distribution board on which a number of pairs of fuses will be situated, perhaps one for each three or four lighting circuits, and one for each power circuit. An exception to this latter rule is the use of a ring main power circuit, which simplifies wiring and which is provided with fuses at both ends. Sometimes the actual plugs used to connect apparatus to sockets installed on this ring main contain separate fuses of their own.

In large installations, the main fuse board will contain master fuses for complete floors, and the connections from these master fuses will run to sub-distribution boards nearer to the loads, installed at convenient points on the floors or sections of the installations.

It is always advisable to sub-divide the fusing arrangements as far as possible, so as to ensure that one piece of faulty apparatus, which causes excessive currents to flow, cannot give rise to widespread supply failure. Fuses must always be carefully graded. In a typical instance a 5-ampere fuse might be installed on a sub-circuit feeding three or

four lamps, and six or eight of these circuits might be fed from a sub-distribution board. This board, in turn, might be fed from a main distribution board with 60-ampere fuses. If the lighting circuit fuse were to blow through a defective lampholder in a standard lamp, and a careless maintenance man repaired the fuse with a 60-ampere fuse wire, the next time a lampholder on that sub-circuit became defective, a current of 60 amperes would have to flow in the flexible cord connecting the lampholder to the skirting socket, and this might well heat up the flex sufficiently to cause it to smoulder before the fuse would fail. In addition, the 60-ampere fuse on the main distribution board would also be likely to blow with the result that a whole floor, perhaps of a large hotel or office block, might be plunged into darkness (Fig. V, 18).

In the case of domestic fuse boards, it is essential to ascertain the proper size of fuse wire used for each circuit, and then to keep handy a supply of wire of the correct size.

There is a considerable tendency to use cartridge fuses on domestic installations and in small factories, while for the larger fuse gear installations this type of fuse is almost universally employed. The cartridge fuse consists of a ceramic tube, equipped with tinned brass caps at each end and filled with sand. The fuse wire is suspended between the caps and when it blows the sand absorbs the gases produced by the fusion of the wire, with the result that perfect safety is achieved. The cartridge fuse also has the advantage that the size of fuse holder is such that an incorrectly rated fuse cannot be inserted under any circumstances. Moreover, many types of cartridge fuse are equipped with an indicator which shows when the fuse has blown, and this is a great advantage in emergencies.

The fuse has many advantages and can be used up to very high currents and voltages but cannot be set to operate at an exact value where extreme precision is required. Moreover, many types of electrical circuits involve constant overloading and fuses would be blown too frequently to be practical. Thus overload relays are widely used. Basically an overload relay consists of some form of electromagnet in the coil of which the main current is made to flow. The electromagnet attracts a moving arm which makes a contact when it has advanced to a predetermined point. This contact closes the circuit of a trip coil, which is another electromagnet designed to pull out a "trip catch" in the linkage of the circuit breaker controlling the circuit which then opens and removes the overload.

Overload relays of many types are used for protecting power systems as in the majority of cases it is impracticable to carry the main

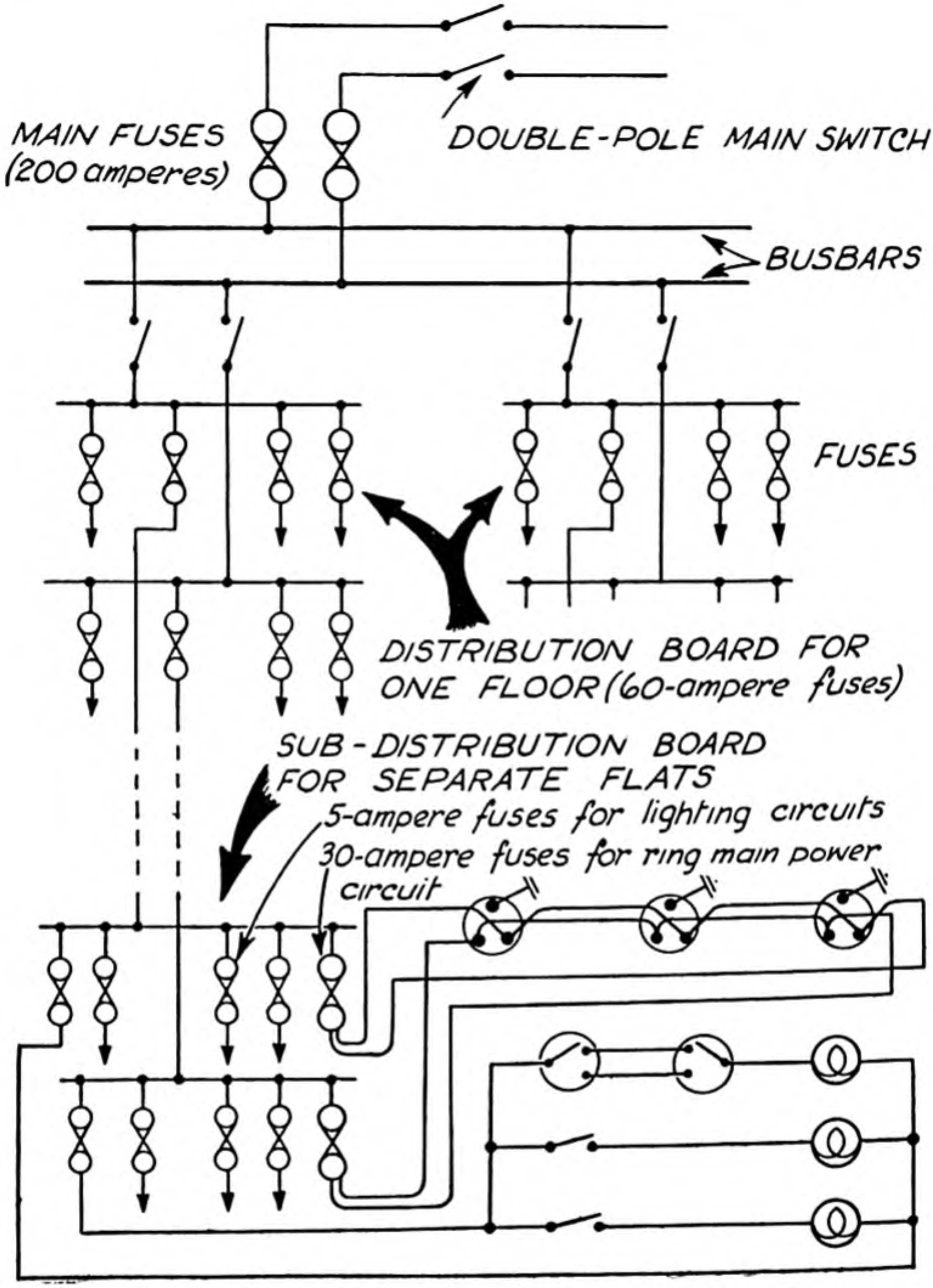


Fig. V, 18.—Fusing arrangements for a block of flats

current itself through the relay coil. Thus a current transformer is used, and the main current passes through a single turn on this transformer. The secondary winding contains a number of turns and is connected to the relay coil. The transformer is so designed that, say, for every 50 amperes of current in the main circuit 1 ampere will flow in the secondary circuit. If the relay is designed to trip at 2 amperes (that is,

to make contact when a current of 2 amperes flows in its coil) it will then operate when 100 amperes flow in the main circuit.

Other types of relay can be used to protect against over-voltage, reverse flow of current, and no voltage. Relays can also be designed to detect leakage currents. If the insulation of an appliance is becoming faulty, but is not sufficiently bad to allow a power current to flow and operate the fuse or over-current relay, the apparatus may still be dangerous. A leakage relay can be arranged to detect this condition before it reaches dangerous proportions, and then can trip out the circuit concerned.

CHAPTER VI

MEASURING ELECTRICAL QUANTITIES

THE electrical quantities that we most often require to measure are: voltage, current, power (in watts or kilowatts), frequency and resistance. Instruments are available to measure each of these quantities and a special class of instrument known as the "universal" meter can be arranged so that it can measure all of them by suitable switching arrangements within its own case. The majority of instruments most commonly used employ the electromagnetic effect of the electric current to provide an indication on a scale which shows the value of the quantity measured.

The two most widely used types of instrument are the moving coil and the moving iron designs.

In the moving coil instrument a permanent magnet, usually of a horseshoe shape, is provided and between its poles there rotates a small coil of fine wire, mounted on a pivot, and having hair-springs at each end which serve the dual purpose of controlling the action and of passing the current into and out from the coil. The current in the coil causes it to become a magnet and its north pole then tends to be attracted towards the south pole of the permanent magnet. The pointer is mounted on the pivot shaft, and thus moves across the scale to a distance which is proportional to the current flowing. As the permanent magnet is obviously polarized, the whole instrument is polarized and current can only be allowed to flow in one direction; if it should flow in the reverse direction the instrument pointer would be forced back against its stop (Fig. VI, 1).

In its essence, the moving iron instrument comprises a solenoid, or coil of wire wound on an iron core, so situated that a pivoted iron vane is attracted into the solenoid when current passes. The iron vane may be restrained by means of a hair-spring, similar to that used in watches, so that when the current falls, and the pull of the solenoid

is consequently lessened, the hair-spring will draw the pointer back towards zero.

In practice the moving iron instrument frequently takes the form of a design which employs two iron elements, one fixed and one pivoted and carrying the pointer, both being magnetized by the same coil. As similar poles repel each other, this repulsive action is used to move the pointer.

The pull exerted by a solenoid is not directly proportional to the current due to the magnetic characteristics of the iron parts employed. In consequence, the pointer will not move over equal distances on the scale for equal increases in current. Thus the scale is not uniform and

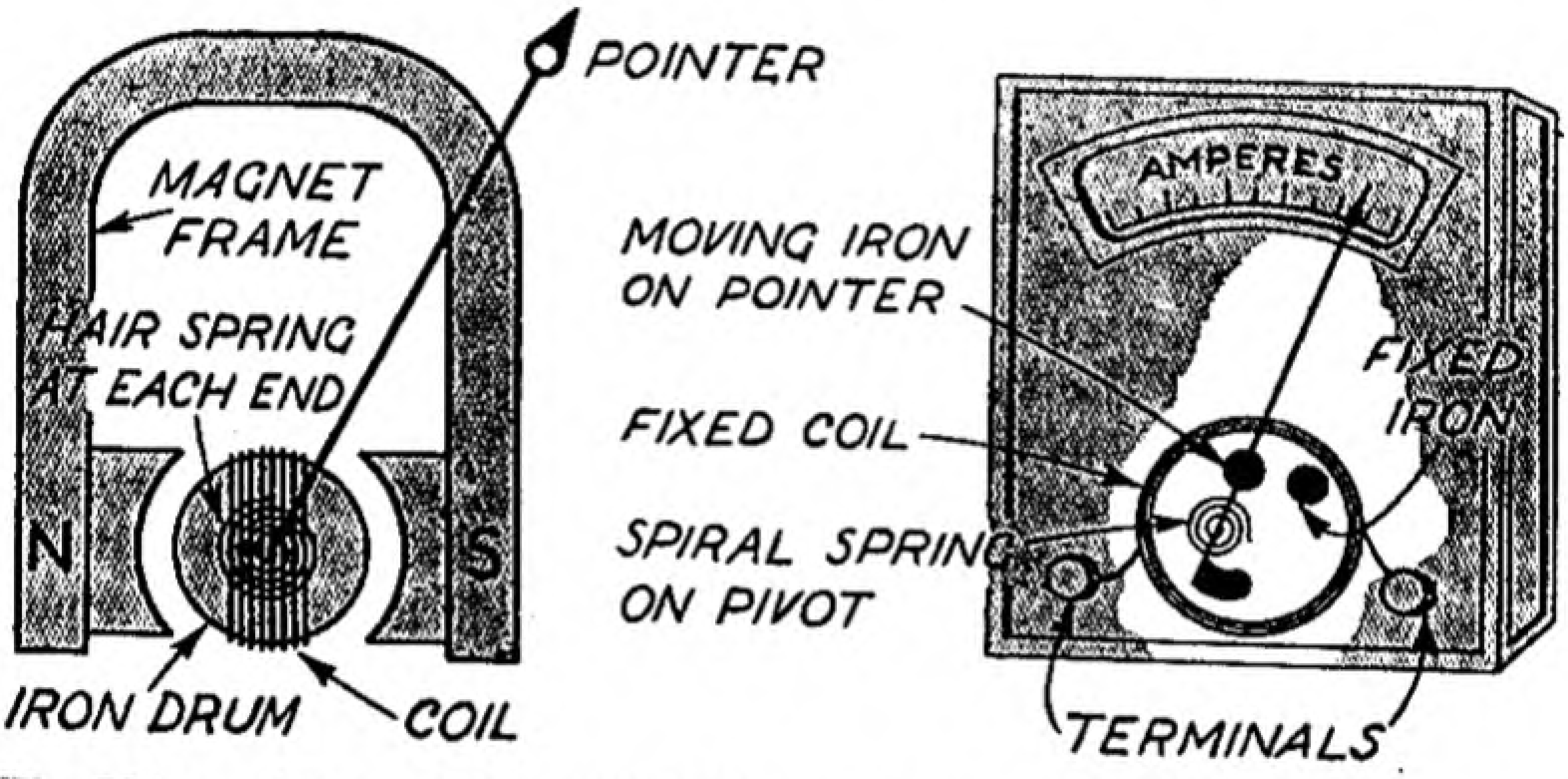


Fig. VI, 1.—The moving coil (left) and moving iron instrument designs

is compressed towards the zero end and more "open" (a larger distance between unit marks) towards the full-scale position.

The mechanical construction of both designs includes jewelled bearings at the top and bottom of an axle on which both the moving vane and the pointer are mounted, and there may also be a damping device which takes the form of a small additional vane moving in a sector-shaped enclosure and so shaped as to act as a piston within this enclosure. The resistance of the air in the enclosure provides a damping force so that the needle does not swing wildly to and fro at every change in current, but instead takes up its position at once.

The pointer may be of the arrow type or it may be shaped like a knife edge and may be arranged to move over a section of mirror glass, set just below the scale, to prevent errors due to parallax. This phenomenon could cause errors if the eye did not line up the pointer

and the scale marking but instead looked at them from an angle so that a reading two or three degrees away from the true reading might well be recorded. If a mirror is fitted, the eye looks straight downwards at the pointer until the knife-edge portion obscures its own image in the mirror, and there is then no doubt that a true reading is being obtained.

The movement may be enclosed in various types of casing. If there are external magnetic forces likely to be encountered (as when the instrument is mounted on top of a generator), a magnetic screen is essential. This may take the form of an iron case for the instrument, with a glass window through which the scale is observed, or if a wooden or plastic case is used a built-in sheet-iron screen may be necessary. Switchboard instruments usually have a very wide-scale arc perhaps extending to as much as 120° or even more. Portable instruments have scale arcs of 70° to about 110°.

The moving coil instrument can be made to possess a higher degree of accuracy than the moving iron instrument, but if it is to be used on alternating current circuits, it is necessary to introduce a rectifier to cut off the current which flows in the reverse direction during each cycle. This is frequently done, but increases the cost and may reduce the accuracy. The moving iron instrument on the other hand can be used for either a.c. or d.c. current or voltage, but there is a type of moving iron instrument in which the moving vane is arranged to work against a fixed permanent magnet, and thus this instrument also becomes polarized, and cannot be used on a.c. without modification.

There are also variants of these two basic electromagnetic instruments in which both the fixed and moving parts are electromagnets. These are known as the electrodynamic and induction types of instrument. They tend to be more expensive than the simpler types but may be needed where very high accuracy is required or when the instrument has to deal with varying frequencies. As a general rule the moving iron instrument is not accurate on frequencies other than those for which it was designed. The rectifier type of instrument, in which a moving coil is used, is able to give a reasonably accurate reading over a wide range of frequencies.

Before considering the quantities that may best be measured by the different types of instruments, it is desirable to touch on the difference between a voltmeter and an ammeter. As we have seen, most instruments depend for their action on the magnetic effect of the current in the coil. Thus, whether we wish to measure voltage or current, it will really be current only that we shall be using to actuate our instrument.

If current is to be measured by an ammeter, then we can pass either the full current or only part of it through the instrument coil. It is obviously impossible to wind the coils associated with the precision-type movements of delicate instruments with wire suitable for carrying hundreds of amperes. The problem of providing a fraction of the main current for the use of the instrument is solved differently for a.c. and d.c.

For d.c. instruments a device known as a shunt is used. In the main circuit is inserted a short length of a special resistance material chosen so that its resistance varies as little as possible with temperature, and the resistance value is so arranged that there is a drop of perhaps 0·01 volt when the full current is passing in the main circuit. To the ends of this shunt is connected a voltmeter which is so scaled that it reads in terms of amperes in the main circuit, since the greater the current the greater the voltage across the shunt and the higher the reading of the instrument.

For a.c. instruments a current transformer is used. This takes the shape of a very accurately made iron-cored transformer, with perhaps only a single turn in the primary winding (for very large transformers the primary copper connection may be taken directly through the ring of iron forming the core, which has the same effect as a single turn). A secondary winding is so arranged that when it is, in effect, short circuited through the instrument coil, it will produce 5 amperes (for example) when full load is flowing in the primary circuit. A current transformer of this type would be described as having a ratio of "1,000/5". Thus the instrument only has to deal with 5 amperes, but at all times the current through it is strictly proportional to the current in the main circuit (Fig. VI, 2), which at full load would, in this case, be 1,000 amperes.

Turning now to voltmeters, the problem here is to measure the voltage in a circuit by means of an instrument that takes account only of current. If we consider a simple d.c. circuit, and we apply across its terminals a suitable resistance, the current, which flows according to Ohm's Law, will be directly proportional to the voltage, provided the resistance does not change. If we have an instrument, of the simple moving iron type, in which the coil is wound with a large quantity of fine wire, thus possessing a much higher resistance than an instrument wound with a relatively few turns of thick wire, we shall have produced a voltmeter that measures voltage through the effect produced by the current the voltage causes to pass in the coil. There is another way in which this can be done. The coil of the instrument may be of the same type as for an ammeter, but in series with it there may be connected a resistance of such a value that when the full circuit voltage is applied

across the ends of the combined circuit, the current which flows is that which creates full-scale operation of the pointer.

In practice, it is possible to arrange an instrument with a number of resistances connected to the coil as required by means of a rotary switch. For example, a particular voltmeter might be arranged so as to have full-scale ranges of 100, 300, and 500 volts. Three separate

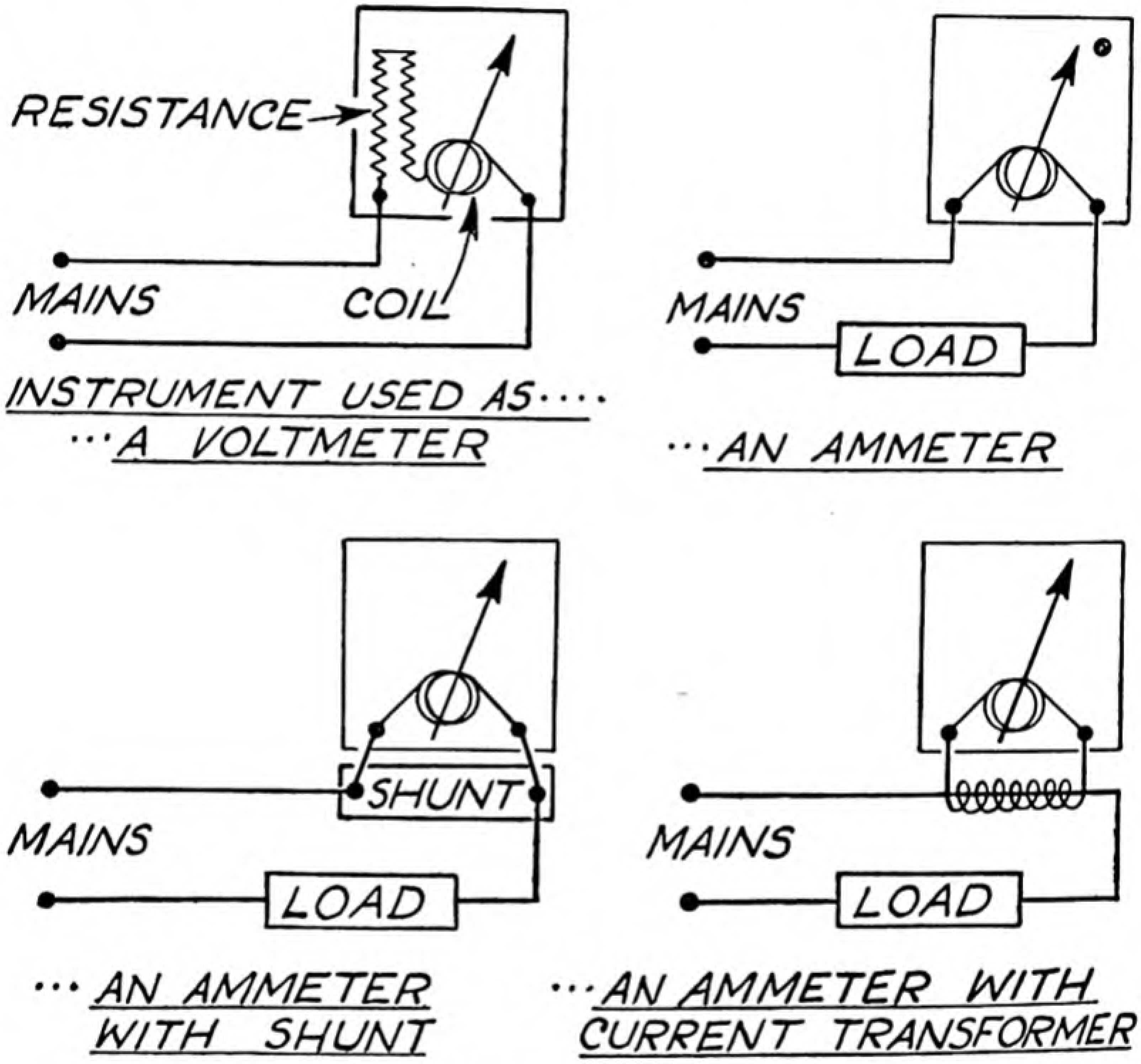


Fig. VI, 2.—The connections used for voltmeters and ammeters

resistances would be provided, of ohmic values such that when the first was switched into circuit, the current through the combined circuit of resistance and coil was such as to move the pointer to the end of its travel. By moving the switch to the second stud, a greater resistance would be introduced, so that when the instrument was connected to a 300-volt circuit the current would be limited once more to the proper current for full-scale deflection. Finally, when measurements up to 500 volts were needed a still greater resistance would be switched in.

To sum up the differences between ammeters and voltmeters,

the ammeter measures current directly by passing the whole of the circuit current (for small currents) directly through the coil of the instrument, or a proportional fraction when large currents have to be measured. The voltmeter on the other hand acts through a conversion of the voltage value to be measured into a current value which is strictly proportional to the voltage whatever value this may have.

The aim of the instrument designer is to provide an instrument as accurate as possible and at the same time consumes the minimum of energy since an instrument which dissipated an appreciable amount of power within itself would not only be wasteful but could very probably affect the current or voltage to be measured by itself providing an additional burden on the circuit. For voltmeters a figure of 1,000 ohms per volt recorded is common, which means that a voltmeter with a full-scale reading of 500 volts would have an overall resistance of 500,000 ohms and would require in consequence a current of 1,000th of an ampere (1 milliampere) for full-scale deflection.

Another effect of the electric current is used for instruments that have to read on all frequencies. This is the heating effect and such instruments are known as the hot wire type. The movement is quite different in design from that of the electromagnetic instrument. A thin but strong wire, which is not affected by high temperatures, forms the basis of the instrument, and it is through this wire that the current passes. The wire is fixed at both ends and as the current increases the wire expands. Attached to the centre of the wire is a second piece of wire which passes over a pulley and is then attached to a spring. The pointer of the instrument is fixed to the spindle of the pulley. As the current increases, the hot wire sags to a greater extent, and this sag is pulled out by the spring exerting its tension on the wire which runs round the pulley. In doing so, it rotates the pulley and consequently moves the pointer. As the ambient temperature of the room in which the instrument is used would obviously affect its reading, the hot wire is mounted on a metal baseplate, with suitable insulating arrangements, which is so arranged that it itself expands to a degree similar to that of the hot wire, when no current is passing. This arrangement compensates to a very considerable degree for changes in ambient temperature. As the heating effect is employed, the instrument is suitable for use on a.c. and d.c. and for any frequency. The instrument, however, suffers from the fact that its overload capacity is small and the hot wire may easily be burned out if too much current passes. It also tends to be expensive.

Another type of instrument, the electrostatic voltmeter, operates on yet another principle. There has been little room in this book for

dealing with electrostatics, which is that branch of electrical science concerned mainly with bodies which are charged with electricity, but where current does not flow until they are discharged. Briefly, as positive poles are attracted to negative poles, and vice versa, so also bodies positively charged are attracted to bodies negatively charged. If two very freely pivoted vanes, not connected to each other, are brought near together, and if one is charged positively and the other negatively, they will tend to move together. In the electrostatic voltmeter, one fixed vane is provided and one moving vane, the effect being the same as if both vanes could move. The pointer is attached to the moving vane. If the two poles of the circuit are connected to the fixed and moving vanes respectively, the pointer will move over a distance corresponding to the force of the electrostatic attraction due to the voltage in the circuit. The instrument has the advantage that no current passes, and thus its own consumption of power is nil; and for certain circuits in which very small powers are concerned this may be of considerable advantage. The instrument can only be used as a voltmeter, as it cannot measure current, and it is not available for low ranges, say below 100 volts, as the electrostatic force would be too low and the instrument could not be made to register satisfactorily.

Measuring Energy

To measure power we must measure the effect of two varying quantities, in place of the single varying quantity dealt with by the instruments mentioned so far. Power is expressed in watts, which are the product of volts multiplied by amperes. The dynamometer type of instrument, which was mentioned previously, as a variant of the moving coil type, comprises a fixed electromagnet within whose field there moves a pivoted electromagnet. If, in a simple d.c. circuit, the current was carried through the moving coil of such an instrument and the fixed coil was connected, with a suitable resistance in circuit, across the positive and negative poles, we should have the possibility of measuring the power in the circuit. An increase in voltage with a steady current would cause the pointer to deflect further, an increase in current with a steady voltage would also have the same effect; and an increase in both would result in a cumulative action. This is the basis of the wattmeter, but whereas for a d.c. circuit an instrument connected as indicated above would give accurate readings, in the case of an a.c. circuit the power factor has to be taken into account. We need to measure the product of the voltage and the *useful* component of the current. This is carried out in the case of an electro-

dynamic wattmeter for a.c. circuits by arranging for the two coils—the coil connected to measure the voltage and the coil measuring the current—to be physically arranged so that account is taken, in the pointer reading, only of the product of voltage and useful current component.

Frequency

Frequency meters may be of several types, depending on the range of frequency which it is desired to read and the accuracy necessary.

For frequencies in the normal commercial ranges, which include the 50 c/s and 60 c/s standard frequencies, and other frequencies up to about 400 c/s, the simplest form of frequency meter is that in which tuned reeds are used. A reed can be so made that it will vibrate intensely at one particular frequency, just as the stretched wire on a piano gives out a note of a particular frequency when struck. An electromagnet connected to the supply system is positioned near a range of reeds which for a 50 c/s meter might run from 48 c/s to 52 c/s by 0·1 c/s intervals. The electromagnet causes a varying magnetic attraction on all the reeds but only that one which is designed to vibrate strongly at the particular frequency of the system will in fact be set in motion. The ends of the reeds are coloured white and are seen through a window in the instrument case. The remaining reeds will appear as thin stationary lines, while the reed which is vibrating will be seen as an extended blur of white against the dark background.

This type of instrument is still used, but for greater accuracy an instrument having a pointer moving over a scale is often preferred. There are several types of such instrument and usually they are based on resonant circuits, which are in effect the electrical equivalents of the tuned reeds. A circuit is arranged so that it is resonant at the normal frequency of the circuit to be measured, say 50 c/s. At this point no current can pass and the instrument although reading 50 on the scale is in fact in its zero position. If the frequency falls the pointer will be deflected to the left and if the frequency increases it will move to the right, as the balance of the resonant circuit is upset, and more or less current will flow through one or other of the two elements comprising the movement of the instrument.

Power Factor (*see* p. 77)

To measure the power factor in the circuit an electrodynamic instrument may be used with the current flowing through one element

and the voltage producing a current in the other. The physical design of the instrument is such that when these two elements produce fields that are in phase—which means that the power factor is unity, and the current is in phase with the voltage—the pointer will read 1·0. As the power factor in the circuit changes, the fields set up by the two moving elements will also move out of phase with each other and the pointer will be deflected accordingly.

Integrating Meters

So far we have considered "indicating" instruments—those that give an instantaneous reading of the quantity measured. When we come to consider the measurement of the amount of energy supplied over a period to a consumer, we find it necessary to introduce the time element and such meters, the kilowatt-hour meters, are known as "integrating" meters because they integrate the reading over a given period.

The normal house service meter installed on every consumer's premises is an integrating energy meter, and its principle is an electric motor of which the speed is strictly proportional to the current flowing in the circuit combined with the voltage across it. The usual construction of kilowatt-hour meters takes the form of a disc on a spindle which is very freely pivoted, usually with a jewel at one end if not both, and which takes the place of the short-circuited rotor in a squirrel-cage motor (Fig. VI, 3, and Plate 16). There are two stator coils, one carrying the current in the circuit and the other connected across the circuit and carrying a current proportional to the voltage. The interaction of the fields produced by these two coils results in a current being induced in the metal rotor disc; and this current gives rise in turn to a magnetic flux which produces, by attraction and repulsion effects in conjunction with the other two fields, a torque resulting in rotation. If either the voltage or the current increase, the torque will increase and the speed of rotation will increase. If both voltage and current increase, as in the case of the wattmeter described earlier, the action will be cumulative. At the top of the spindle carrying the rotor is a worm-wheel that drives a pinion coupled to a gear train which in turn drives the pointers marking the passage of one-tenth of a unit, one unit, tens of units, hundreds of units, and thousands of units, the gear-wheels being arranged so that each successive pointer is geared down by ten to one. As an alternative to the pointers, a cyclometer type of dial arrangement may be employed, with number wheels showing a single number through windows, the number wheels moving on as the gear train drives them round.

It may be worth while mentioning here that when reading the pointer type meter, the reading which should be written down is the last figure passed by each pointer.

The final element to be mentioned in a kilowatt-hour meter is the braking arrangement. If no form of brake were provided, the meter would continue to run on even when the circuit in which it was connected was switched off. As every possible step is taken to reduce

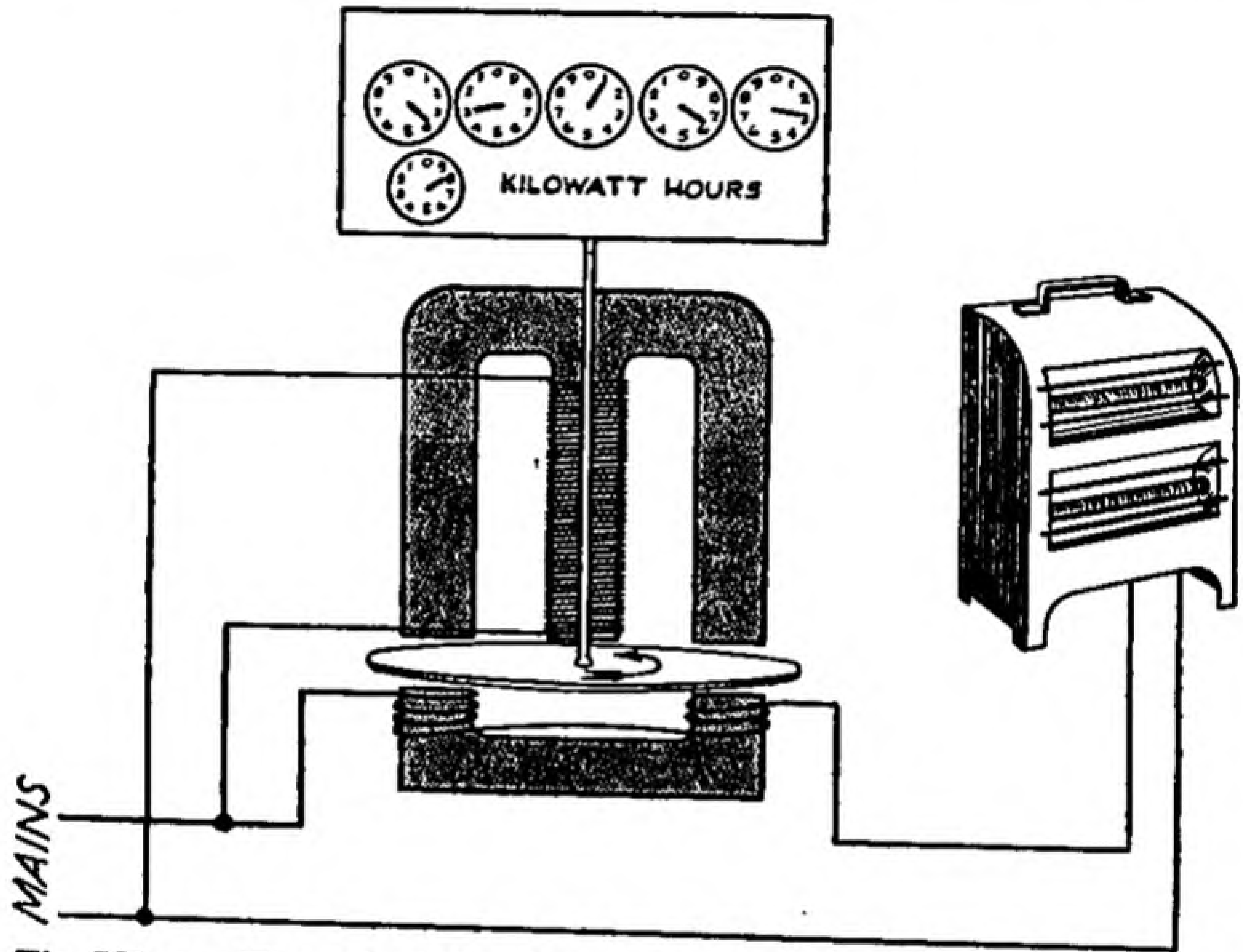


Fig. VI, 3.—The principle of the energy meter. (Note: the magnetic brake is not shown: *see* Plate 16)

friction, the rotor might take half an hour or more to come to a stop, and all this time it would be registering units. To prevent this, a permanent magnet is so arranged that its poles are brought very closely together, one on each side of the rotor disc. As the rotor revolves, it provides the effect of an elementary dynamo as a moving conductor —the rotor disc—cuts the lines of force of this braking magnet. Whenever a dynamo is put to work, energy is needed to drive it; and this rather special form of generator is no exception. The energy needed to operate this very small dynamo is the braking torque of the meter. In normal running the meter is so calibrated that as it works against the braking torque its readings are accurate. Directly the driving

torque ceases to operate, when the circuit is switched off, the braking torque takes charge and stops the rotor almost instantaneously.

The form of kilowatt hour meter described is that suitable for a.c. circuits. Very few equivalent meters are now needed for d.c., but such meters are operated on the same basic principle, though a commutator for the moving coil is necessary.

For three-phase a.c. circuits special forms of kilowatt-hour meter having two—or occasionally three—separate motor type movements on the same shaft are employed, the total power in the circuit being in effect added up from the separate readings in the phases, and recorded on a single set of dials.

RESISTANCE

To measure resistance, the usual method is to make use of either a bridge circuit, or a special insulation tester which employs the Ohm's Law principle.

The Wheatstone bridge is a form of electrical circuit in which two parallel paths carry a current, and if these two are of equal resistance, per unit length, the voltage drop across each unit of length will be the same in each (Fig. VI, 4). Thus if a voltmeter is connected from the mid-point of one of the two parallel paths to the mid-point of the other (A, A_1), there will be no reading since the voltage drop will be the same in each case, and the two points will be at the same potential. If a different resistance is introduced into one of the two circuits, in place of the first half of the normal resistance path, then the balance between the two centre points will be upset, and there will be a reading on the voltmeter. If the terminals of the voltmeter are now moved along until zero reading is once again achieved, the point at which this condition has been reached (B, B_1) will provide an indication of the ratio of the unknown resistance to the known resistance.

The Wheatstone bridge may be made up as a portable instrument supplied from a battery and employing a simple galvanometer to give the necessary zero indication. A galvanometer is a simple form of instrument in which a magnetized pointer, pivoted in the centre, moves at the centre of a coil which carries the current in the circuit. If the coil is magnetized by the passage of the current the needle will move.

Very delicate galvanometers employ a moving coil with a permanent magnet, and the coil may be suspended on very fine flat strips of metal, which convey the current to and from the windings,

one of the strips carrying a very small mirror which reflects a spot of light which in turn moves over a scale. Instruments of this type are extremely sensitive and will operate when fed with currents nearly as low as one millionth of an ampere.

The second type of resistance-measuring instrument, and the one most commonly in use outside the laboratory, is known as the Megger. It is based on the Ohm's Law principle that the greater the resistance in a circuit fed by a constant voltage, the less the current. A portable generator comprising a coil moving between the poles of a magnet, and providing a d.c. output from its commutator, forces current through the unknown resistance which is connected in series

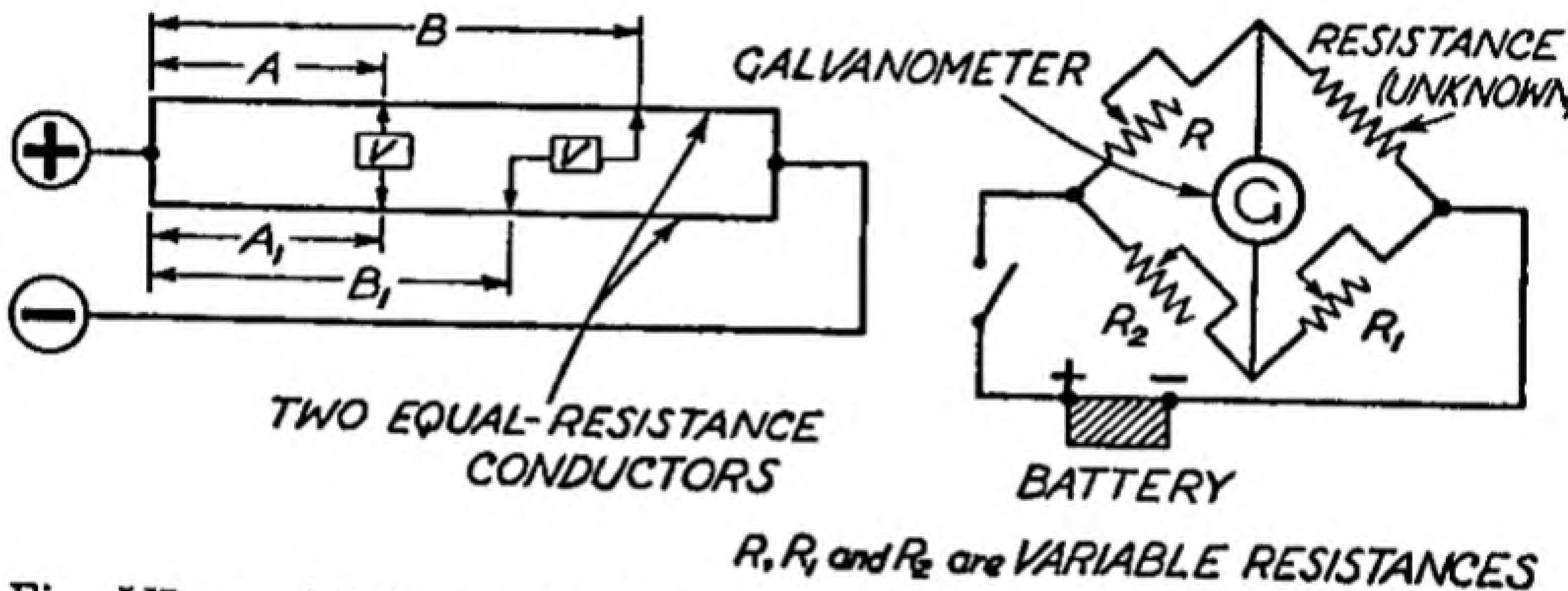


Fig. VI, 4.—Methods for the measurement of resistance; right, the Wheatstone bridge

with the coil of a moving coil instrument. As the voltage of a hand-driven generator depends on the speed of rotation of the handle, it cannot be regarded as constant, and thus special measures are taken to enable the instrument to provide an accurate reading. These consist of the provision of a compensating coil which forms a second moving coil within the field of the same permanent magnet, and which has the effect of providing an increased reading of the pointer if the voltage is low, and a decreased reading if the voltage is high. In addition there is a clutch of a special type on the handle of the generator, which will slip if the handle is turned too fast. These instruments may be arranged to read millions of ohms, and are extremely useful particularly for checking the insulation resistance of an electrical circuit.

The universal test meter, which is very widely used in workshops and indeed everywhere where the highest accuracy is not required (except where an instrument must always be left in circuit as in power stations), comprises usually a basic moving coil movement, to which

a large number of modifying circuits may be connected by means of switches or plugs.

A universal instrument may be used as a voltmeter for a.c. or d.c., an ammeter for a.c. or d.c., and an ohmeter for measuring resistance. For d.c. measurements, a series of resistances and shunts, embodied within the instrument case, are used to give the various ranges of reading. When the instrument is to be used on a.c., a rectifier is brought into circuit by changing the switch to a.c., and while the same resistances as for the d.c. circuit will serve for the various voltage ranges, current transformers are brought into circuit for the a.c. current ranges. To measure resistance, a small battery is situated inside the instrument, to provide the necessary voltage, and will be connected in series with the movement connected as a milliammeter and the unknown resistance.

Use of Meters

In using any type of electrical meter it is essential that certain precautions should be taken. First, the instrument should be examined to see that it is suitable for the system—a.c. or d.c.—or for the probable voltage or frequency of the circuit on which it is to be employed. Failure to make certain that this is the case may easily result in the burning out of a valuable instrument, or it may mean the readings obtained are completely inaccurate. Most instruments have marked on them, usually at the bottom of the scale, an indication of the type of instrument or of the limitations applicable. For example, a moving coil instrument without a rectifier must not be used on a.c.

If an instrument has a number of ranges, precautions which are always desirable consist first of trying the instrument out on the highest range, even if it is known that the reading desired will lie within a lower range. Secondly, if there is an unexpected zero reading on one range, the instrument should be tried out on the other ranges, with discretion, to ensure that the range-changing switch is not defective or that the resistance or shunt or transformer on that range has not become burnt out or disconnected.

Most instruments are provided with a small screw on the front cover, usually in the centre, for zero setting. As the instrument is carried about, slight shocks may upset the zero point on the scale or a change in electrical characteristics may also affect the instrument. The zero point on the scale is the point at which the needle should come to rest when the instrument is not connected to the circuit. If it rests at any other point, it may be brought back to zero by a slight adjustment

of the zero setting screw. This screw should be moved with great care and gently turned a very small amount in one direction or the other. Forcing it too far in either direction may easily damage the delicate hair-springs of the movement. The zero setting should not only be checked before the instrument is used, but should be looked at occasionally during use as it may change when the instrument warms up as current passes through its coils.

Electrical instruments are, in general, to be regarded as delicate pieces of apparatus, and should never be dropped or roughly handled. They should be kept dry, and if they have to be transported frequently should be carried in suitable felt-lined cases to prevent vibration and jarring. They should not be subjected to extremes of temperature and care should be taken to prevent the permanent magnets with which most of them are equipped from becoming de-magnetized or affected by strong external magnetic fields of any sort.

CHAPTER VII

ELECTRICITY SUPPLY; ELECTRICAL RISKS

SINCE everyone in Great Britain (and in most industrialized countries) is nowadays dependent on electricity supply for most of the amenities of life and for the power for his factory or workshop, however large or however small, it is necessary for all to be aware of the organization that brings a supply of electricity into our homes and factories.

Before 1930 there was no national co-ordination of electricity supply in Great Britain. Since the establishment of the first municipal power station in Bradford in 1889, company and municipal enterprise had built up a series of electricity supply undertakings, some large and some small, which covered the whole country, and were loosely controlled only as regards safety, powers to give supply on a monopoly basis in a particular area and—in the case of municipal undertakings—their financial borrowing powers were subject to government consent.

In 1926 an Act of Parliament was passed which effected a radical change in the framework. As a result of experience in the First World War the Government had grown to realize that electricity played a vital part in the economic life of the country, and that reliance could no longer be placed on a number of isolated power plants. If one of these had been damaged by bombing, the complexity of the repair of the boiler-house and turbine plant would have meant that the area it served might well have been entirely without electricity for weeks or even months. The siting of generating plant was also a vital matter which had to be subject, in the national interest, to an increased degree of control. The 1926 Act therefore was aimed at improving both the reliability of electric supply, and the economic aspects of power generation.

To understand the Grid scheme, which was the central feature of the 1926 Act, we must consider first the basic principle governing the

interconnection of electrical power stations. It will be appreciated that as electricity cannot be stored, at any rate in significant commercial quantities, the demand must be met as it arises. An isolated power station, in the pre-Grid days, would have to have a minimum of two generating sets, each of which could carry the full load if the other set was out of commission owing to breakdown or overhaul. In practice there would usually be three sets because the load varies very widely between night and day and between winter and summer, and to run a single large unit on very light load would be to run it very inefficiently. Thus the power station might contain three sets each, say, of 10,000 kW capacity, two being run during the heavy demand period—in the morning and the evening—one set being on load for the rest of the time, and the third set acting as standby for either of the other two. One result of this arrangement is that one-third of the capital expenditure, which might run in the case of a large station to several million pounds, was idle in the sense of not earning any revenue, for perhaps 90 per cent of its life.

If another town perhaps twenty miles away, exactly similar from the point of view of electrical demand, had a power station almost exactly similar to the one we have described, we can see what benefits would accrue from the laying of a cable coupling the two towns together electrically. The spare set in one town could act as standby for both of them, thus releasing one set which could either be scrapped or—as would be more likely—could be ready to meet new demand without the need to buy more plant. A further and even more important advantage of the interconnection between the two towns is the fact that the running of the two stations could be co-ordinated so that far more efficient operation could take place. For example, during the night hours one set in one of the two power stations could carry the load for both. This would mean that it would be running far more efficiently than would be the case if two sets, one in each power station, were running at very light load.

If three or more towns were all interconnected by cables in the way indicated above, the benefits would begin to increase since a town with, say, its own power station and two cables to adjacent power stations in other towns would in fact have three sources of electrical energy, any one of which could carry its whole demand. A town fed in this way could hardly be put out of action by any sort of catastrophe such as a fire at the power station, a bombing attack, or even by a local strike. In addition, the more power stations were connected together, the more could the load be swung round so that when the combined demand of all the towns was very light, such as during the night hours

on a warm summer evening, one set could supply them all and could be running efficiently at full load (Fig. VII, 1).

It was to put these basic principles of interconnection into action that the 1926 Act provided for the establishment of a National Grid operating at 132,000 volts, and carried across the countryside on the

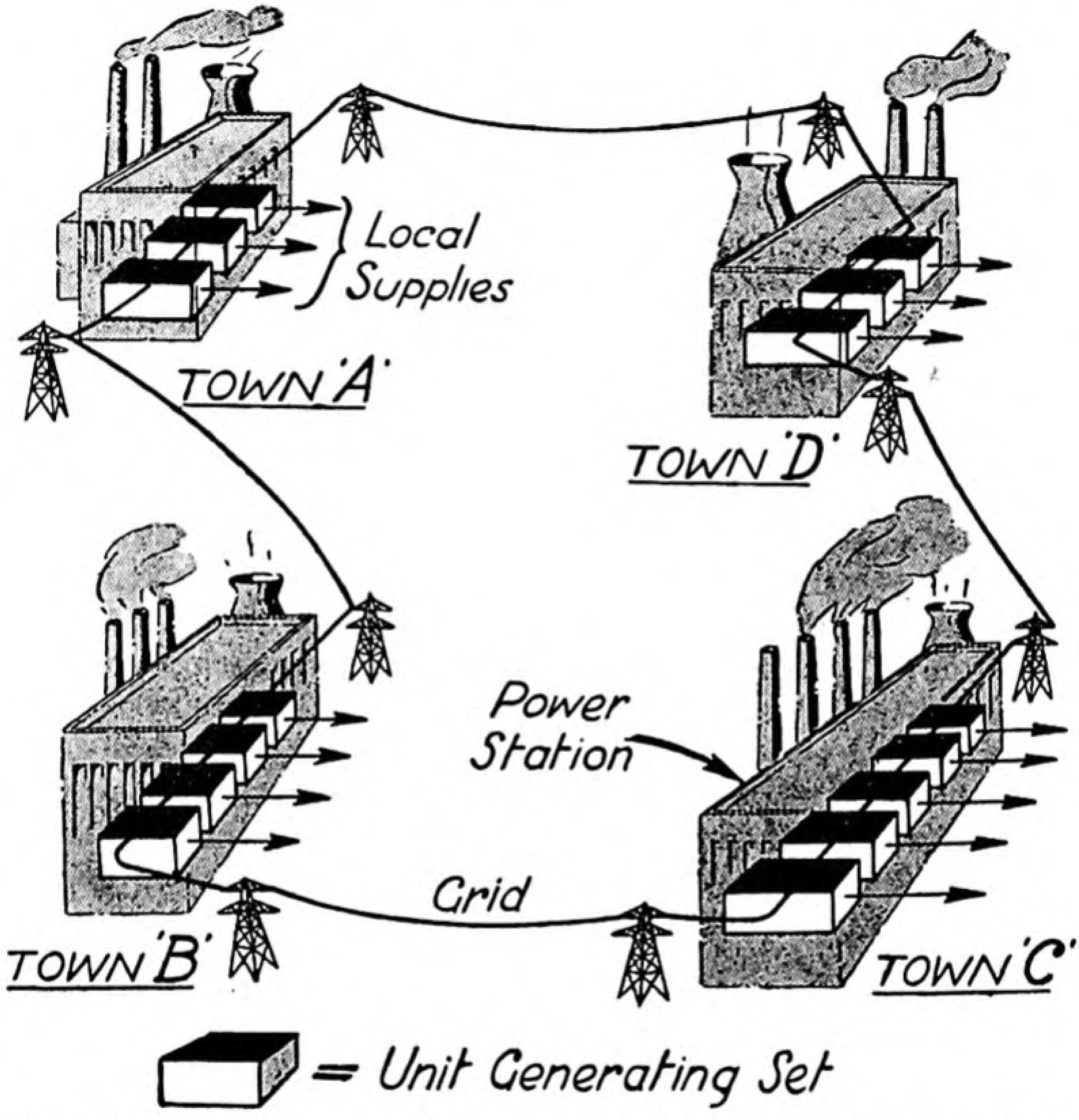


Fig. VII, 1.—Diagram illustrating the principle of the grid system

familiar pylons. It was operated by a body known as the Central Electricity Board, whose functions were to co-ordinate power generation throughout England and Wales and part of Scotland, although they did not own the power stations, and they did not engage in distributing electricity to the consumers. They had legal powers to tell all power stations, at all times, what amount of current they should generate, and all the 570 municipal or company undertakings had to buy their current from the Central Electricity Board. It was the

Board's duty to build and operate the Grid, which in fact consisted of a series of interconnecting cables between all the power stations, and so enabled any demand, whenever it might arise, to be fed from any power plant wherever it might be situated. In this way they could ensure that the most efficient plants generated the maximum amount of current, thus cheapening the price of electricity and conserving coal, and by the aid of their Grid system they could supply any load which arose due to developing industry without the need for a power plant on the spot. (This facility was especially valuable at the beginning of the Second World War when the Government decided to build very large munition factories in South Wales, with a consequent demand for power greatly in excess of the capacity of the local generating plant.)

The Central Electricity Board operated from 1927 until 1948, when the whole of electricity supply in Great Britain was nationalized through the operation of the 1947 Electricity Act. This Act appointed the Central Electricity Authority and the 12 Area Electricity Boards to cover England and Wales. The North of Scotland has its own Electricity authority known as the North of Scotland Hydro-Electric Board, and the South of Scotland, where there exists the South of Scotland Electricity Board, created in 1955.

In England and Wales, the Central Electricity Authority (from 1948 to 1955 called the British Electricity Authority) now owns and operates all the power stations and the Grid system which now includes the Supergrid, operating at 275,000 volts. Their function, broadly, is to act as manufacturers and wholesalers of electrical energy. They can swing the generation from one plant to another, through the medium of the Grid, and can meet the demands of any of the Area Boards, wherever they may arise, from the most suitable power plant.

The Area Electricity Boards fulfil the function of retailers. The consumer is not directly in touch with the Central Electricity Authority, but only with his Area Electricity Board. The Boards in turn are divided into sub-areas and districts. In practice most consumers will take their electrical problems to the District Manager, who is the responsible official for providing them with all the energy they need. Tariffs are fixed by the Area Boards, in consultation with the Central Authority.

There is no law which prevents a person from establishing his own private generating plant, but he must not sell electricity to anyone else. If, for example, in a factory there is a need for a considerable quantity of steam or hot water for the process on which the factory is engaged, it may be economic for the factory management to instal a steam turbine which fulfils the dual function of generating electricity and passing

out the steam needed in the factory. Another factory may decide to instal emergency diesel generating plant of its own. If this is done, the local Area Board will negotiate with the factory owner so that an equitable charge is agreed for running a main into the factory, to act as standby to the factory's own generating plant, and to carry the load perhaps during the night and weekend hours. Obviously payment must be made for the service so provided, since the Area Board has to be ready to supply the current at any moment, and capital costs have been incurred in providing the necessary plant.

The cost of private generation must always be greater than that of public supply, unless water power is available. This is because the high rates of efficiency achieved by modern generating plants, with their very large units and highly skilled staffs, cannot possibly be equalled by the small factory generating unit, or by the petrol or paraffin set at the isolated farmhouse.

Safety Precautions

It is important that everyone concerned with electrical apparatus should understand not only the basic rules for safety when dealing with such apparatus, but also the legal position regarding safety measures on electric installations.

To deal first with the legal position, there is no law that specifies how an ordinary householder must conduct his own electrical affairs; but his insurance policy may well be invalidated if he instals unsafe equipment in his home. The Institution of Electrical Engineers has laid down a code of practice which is universally regarded as being the best possible guide to the installation of all types of electrical wiring and other gear. It may be purchased from the Institution, whose address is Savoy Place, Victoria Embankment, London, W.C.2. This code does not have the force of law, but nevertheless many insurance companies, particularly when dealing with commercial premises, recognize the I.E.E. Wiring Regulations by stating that the policy "is only valid if the electrical equipment is installed according to these regulations". Where such matters as fatal accidents to domestic employees, and the like, are concerned, it is of very great advantage to anyone who might be legally liable to be able to prove that his installation has been laid out according to the I.E.E. Regulations. (A parallel case is the Highway Code, which again does not have the force of law, but which provides a strong defence, if its provisions have been followed, in the case of a dispute as to the liability for a road accident.)

In some countries, as for example in New Zealand, it is an offence

against the law for any unauthorized person to connect any electrical equipment to the mains. Registered electricians have to pass a test of competency and have to agree to follow a rigid code of safety rules. This is not the case in Great Britain, although it has often been suggested as desirable, and may well be made the subject of new legislation. Nevertheless, anyone who proposes to instal electrical equipment which is to be connected to the mains must take the greatest possible care to ensure that the person carrying out this work is competent. The Area Electricity Boards, mentioned previously, have powers to withhold supply from installations not considered safe.

When electrical equipment is installed in any kind of workshop or factory where persons are employed the legal position is very different. The various Factory and Workshops Acts and the Electricity Regulations of the Ministry of Fuel and Power have the force of law, and their provisions must be rigorously followed on pain of prosecution. These regulations are all-embracing, and even the smallest garage with only a single employee is subject to inspection by Her Majesty's Factory Inspectors. It would be unwise, and could easily be misleading, to try to summarize any part of these regulations in this book. The regulations themselves are not difficult to understand, and a wall notice giving their principal provisions has to be exhibited in the factory.

A few general rules about safety when dealing with electrical apparatus may be of use. First, the basic principle should always be to make certain that the apparatus being dealt with is not only switched off, but is physically disconnected from the mains before work is begun. To illustrate the importance of this, the case of an ordinary domestic electric radiator may be considered. Suppose it is of the two-bar type, with a switch controlling the second bar.

The makers will already have arranged for one safety measure—the lack of a switch for the first bar. If such a switch had been provided it would, generally, have isolated the mains from one side only of the first bar, breaking the circuit so that no current flows. Nevertheless, the other side of the circuit would remain connected to one end of the first bar, which might therefore be alive, in relation to earth, even if no current is flowing. The metal frame of the fire should be connected to earth *via* a third and quite separate wire in the three-core flex from the fire to the plug in the wall. Anyone attempting to remove the heating element—for example, if the contacts at the ends had become defective—would run the risk of receiving an electric shock at 240 volts, either by simply touching the element itself and then completing the circuit to the neutral (or earthed) side of the supply mains through a wet floor, or else by a much shorter path from the live element to the

frame of the fire, which, as mentioned previously, should also be earthed. For this reason the makers arrange for the fire to have no switch on the actual frame itself, but to be switched off either by removing the plug physically from the socket in the wall, or by switching off at a nearby switch, which should have been so connected that the "live" wire is broken, leaving the element connected only to the neutral or earthed side of the system.

Regarding the second bar of the fire, it would be equally dangerous to attempt to work on this if it was only switched off, and indeed the only safe way is to remove the plug entirely from the socket, so that no part of it can be possibly made alive.

This principle applies to all electrical apparatus at all times. Switching off is not enough for safety. Some form of physical separation is necessary. In domestic premises and small factories this may be conveniently carried out by removing both fuses controlling the circuit concerned, at the appropriate fuse-box. Once these fuses have been removed, a notice should be placed on the box to show that work is being carried out, otherwise someone else may inadvertently replace them.

Where large electrical apparatus is concerned, it is not only necessary to switch off and isolate the equipment, but it is also essential that it should be connected to earth. To do this special clips and cables are provided to join all parts which might be made alive to a convenient metal part which is solidly connected to earth. The purpose of this provision is twofold. When large electrical equipment has been alive and is suddenly switched off, a residual charge remains, as with a capacitor; and if anyone who stood on earthed metal or on damp ground were to touch such equipment, he would be likely to receive a shock as he discharged this residual charge to earth. The second reason for earthing the equipment is to prevent induced charges. When two wires run close together and one is carrying current, there is a transformer effect between them, and a voltage may easily be induced in the second wire, even though it is not connected to the live system.

There are occasions when highly trained electricians have to work on live electrical equipment, with suitable safeguards. They usually use a rubber mat to stand on, and they employ rubber gloves to insulate their hands. This practice is dangerous for anyone not fully trained. In any case rubber gloves, although extremely useful in certain circumstances, should never be relied on by untrained persons and unless they are constantly tested and inspected they may develop cracks through which moisture can penetrate and can then conduct a charge through the glove from the live wire to the person's hands.

Insulated screw-drivers and other tools are also sources of potential danger in the hands of the unskilled. They may be safe when new or when properly cared for and checked, but the insulation is liable to chip and deteriorate with use. If reliance is then placed on such tools for safety purposes, a severe accident may result.

When the skin is damp it is a much better conductor than when it is dry. For this and other reasons the greatest care should be taken in installing electrical apparatus in all places where there is dampness. For example, in bathrooms bare electric fire elements should never be used at ground level, where a wet towel might come into contact with the live connectors, resulting in a fatal shock. The switches and other equipment should always be of the insulated pattern, so that even if the internal insulation failed, and brought the live wires into contact with the cover, no shock could result.

To conclude this section on safety, it may be as well to give a brief note on emergency action to be taken if a person receives an electric shock.

When a person receives a shock and is not unconscious, he may have severe burns which require immediate first-aid, but he will have removed himself from the live conductor. In many cases, however, the patient is unconscious and is perhaps lying across a broken flex which is alive or is in contact with some other type of electrical apparatus. The first thing to remember is that there is danger of the rescuer himself receiving a shock, and so he must either switch off the supply, or must remove the patient from the live conductor. For ordinary voltages, such as those to be found in the home or in the smaller type of factory (that is, up to about 500 volts), the patient should be pulled away by using some kind of dry insulating material, such as dry rubber or leather gloves, a cap or hat or even dry newspaper, or by dragging him away with a wooden stick or a broom. For higher voltages, it is likely that the patient will be some distance from the wire, as the reaction caused by the shock will tend to throw him clear. If this has not happened, the greatest caution must be shown by the rescuer and it should be remembered that for high voltages rubber gloves are not suitable and ordinary insulating materials, such as those mentioned above, will be quite inadequate to protect the rescuer. Before entering the dangerous zone he should make every possible endeavour to switch off the current, and if this is not possible he should use the longest available dry wooden rod or stick to drag the patient clear of the area immediately surrounding the live portion.

Once the patient is clear of the live conductor artificial respiration should be started immediately.

CHAPTER VIII

IN THE HOME

THE first and most commonly used application of electrical energy in the home is the electric light, the earliest type being an arc-lamp, in which two carbon rods were connected to the two poles of the battery, and after being touched together were slightly withdrawn, so that an arc was formed between them. The glowing points of light from the incandescent white-hot carbons formed the source of light, and provided an artificial illuminant of a brilliance never before seen. The arc-lamp, however, was soon found to be too powerful and too uncontrollable for domestic usage, and for all other purposes than outdoor lighting and special services such as searchlights and lighthouses. The arc-lamp is still used for cinema projectors, anti-aircraft searchlights, lighthouses and similar purposes; and is nowadays also employed, in a modified form, for melting metals in a furnace. Anti-aircraft Command in the 1939–45 war employed arc-lamps which needed 4,000 amperes at the carbons, and consumed 600 kW, needing an engine of nearly 1,000 h.p. to drive the generators supplying each lamp.

In the late 1870s Swann (in England) and Edison (in America) devised the first filament lamps in which the passage of current through a thin thread of carbon caused it to glow red hot, and so emit light. To prevent the thread from burning away, it had to be enclosed in an exhausted glass vessel—the ordinary electric lamp bulb. In the early 1900s a metal filament was made, of tungsten metal, which melts at 3660° (absolute).

As the very hot metal in the filaments of the early lamps tended to evaporate in the vacuum, and become deposited on the glass, thus darkening the lamp, gas filling was soon adopted, nitrogen or argon being used. This gas filling brought in its train the problem of convection currents which caused the filament to lose heat. To prevent this to some extent, the present-day "coiled-coil" lamp was designed.

The fine wire is first coiled in a coil of very small diameter and then this coil is coiled again. The maximum length of wire is thus included in the smallest possible space, to increase the amount of light available and to reduce the effective surface presented to the cooling convection currents (Fig. VIII, 1).

The glass of which the bulb is made can be either clear glass, or else of the frosted or opal type, to provide a better diffusion of the light. Connection to the external electric circuit is made through the lamp cap, which may be of the familiar bayonet type used in Great Britain, and many other parts of the world, or of the Edison screw type, commonly employed in America. The lamp cap varies with the power of the bulb. For the bayonet cap type there are two sizes only, small bayonet cap and standard (S.B.C. and B.C.). There are three sizes of

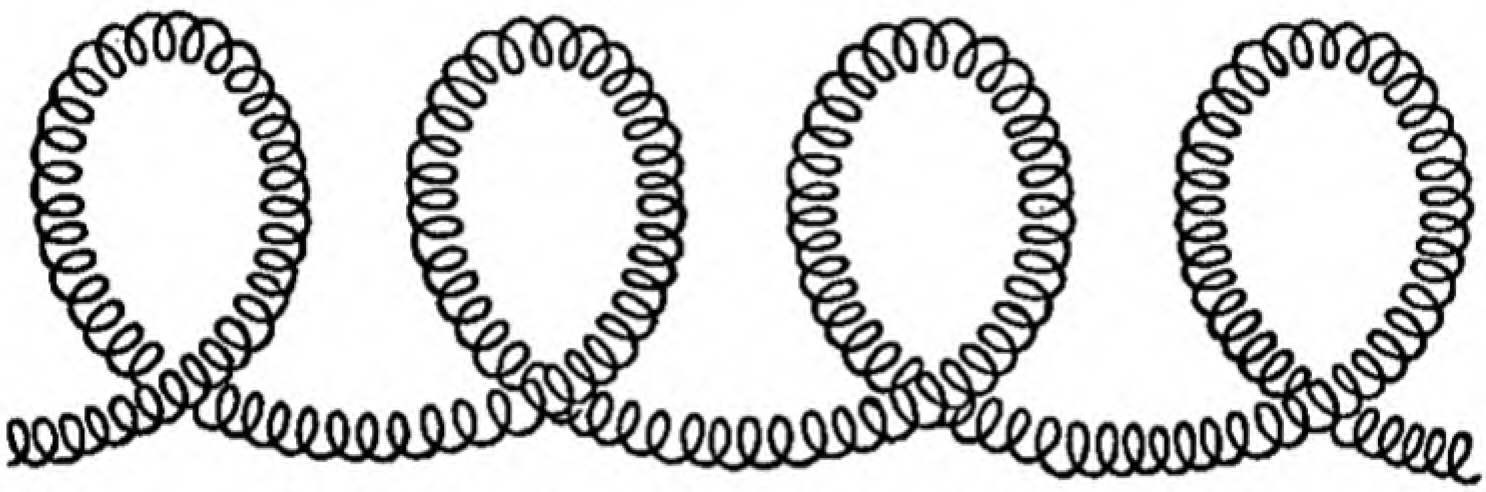


Fig. VIII, 1.—The coiled-coil filament

Edison screw caps. Ordinary domestic lamps have E.S. caps (Edison screw); the large lamps used for outdoor lighting and lighting of factories use the Goliath Edison screw (G.E.S.); and ordinary flash-lamp bulbs are fitted with the small Edison screw (S.E.S.) (Fig. VIII, 2).

There are also certain special types of lamp, with caps at both ends, such as strip lights and architectural lamps of various straight and curved designs. These employ special caps with a single pin for the single wire brought out at each end of the lamp.

Special types of filament lamp include reflector lamps in which there is a built-in silvered reflector, which gives a spot-lighting effect. There are also lamps whose primary purpose is to radiate heat rather than light, and these are the only lamps that still employ carbon filaments.

The neon indicator lamp does not give illumination in a practical sense for lighting purposes but instead provides an indication only for some such purpose as to show whether a circuit is switched on, or the situation of a bell-push. These lamps do not contain a filament, but instead have two electrodes which are connected one to each pole of

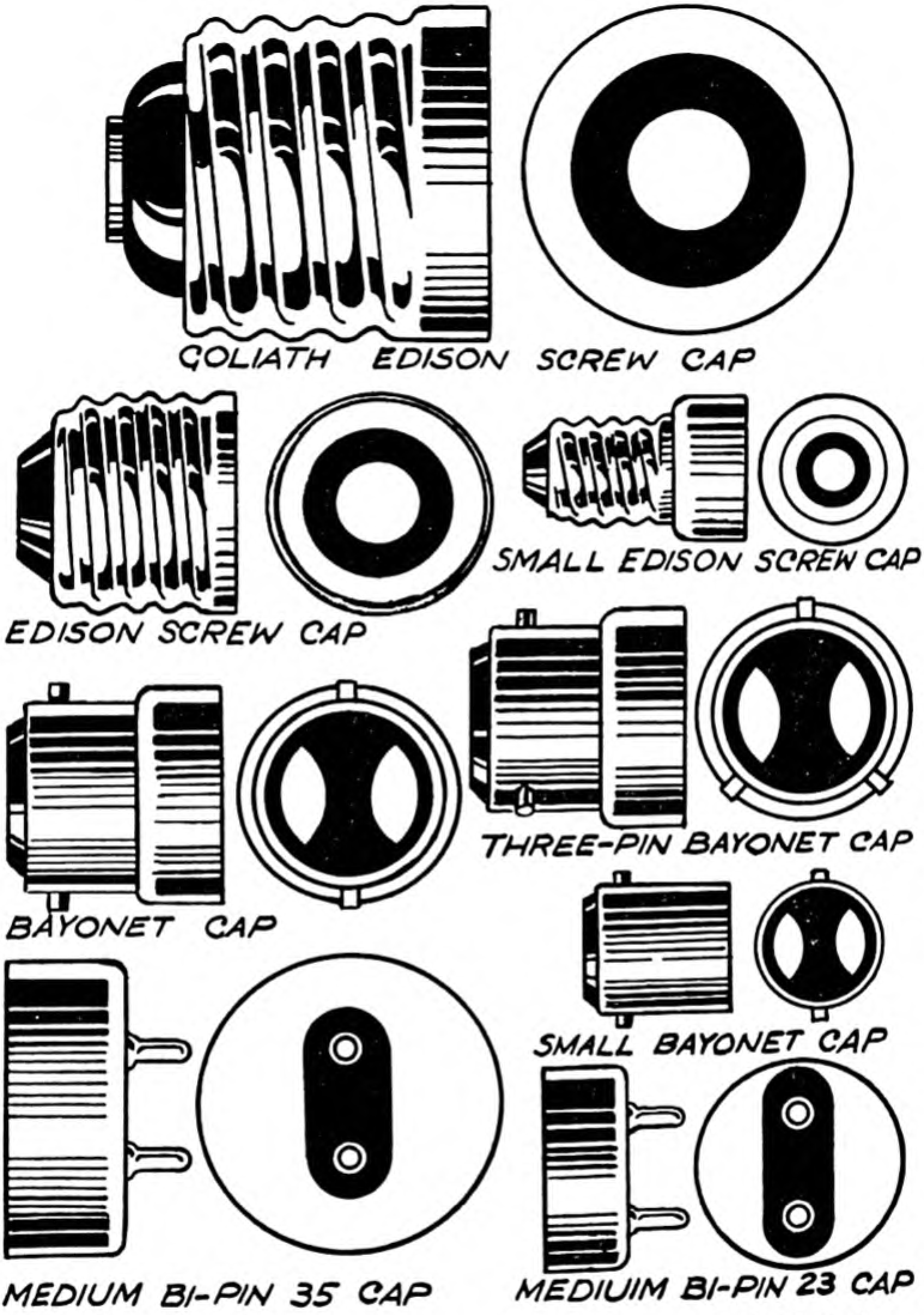


Fig. VIII, 2.—Types of lamp cap (approximately actual size)

the circuit and which are situated in a neon gas atmosphere. As we shall see later, when discussing discharge lamps, the application of voltage under these circumstances leads to a glowing effect, which is all that is required for this particular purpose.

The filament lamp has been developed for ratings from 15 W to

of precautions to be taken when connecting them to the water mains. Excessive water pressure has to be reduced by means of a reducing valve or washer, and in certain cases the water heater may be of the pressure type, in which case overflow connections have to be provided.

The principal maintenance needed takes the form of descaling, as the hot element tends to cause the deposition of scale from hard water, with consequent loss of efficiency. This is shown up by reduced flow, or by the length of time needed to heat the water after the whole of the hot water has been drawn off. In hard-water districts such water heaters should be professionally descaled about once a year.

The second type of water-heating device used in domestic premises is the immersion heater, which is made in sizes up to 3 kW, and which is used mainly in the hot tanks of existing water-heating installations. For example, in a house in which a coke-fired boiler is employed in winter for the dual purpose of providing hot water and warming the kitchen, an electric heating element may be installed in the hot tank for use in the summer or at other times when it is not convenient for the coke fire to be lit.

The essential requirement when fitting one of these heaters is that the tank should be properly lagged. If this is not done, the electricity consumption of the water heater will be excessive, as it will be acting as a radiator and dissipating large quantities of heat into the bathroom or loft into which the hot tank is situated. The lagging usually takes the form of a kapok-filled jacket, designed to fit closely round the tank. The element must be situated in such a position, relative to the bottom of the tank, that free circulation of water can take place.

It is often desirable to fit a pilot lamp, perhaps in the kitchen, so that the user may realize that the immersion heater is switched on; otherwise, it may be wastefully left in circuit when not required.

Another form of electric water heater is the wash boiler, which comprises a galvanized bowl, mounted on a suitable frame, below which is situated a heating element which may be of 2 kW or 3 kW capacity. This element is often fitted with a three-heat switch.

Hair dryers comprise a small heating element, of the resistance-wire type, across which is blown a stream of air from a fan driven by a very small electric motor. The heater and the motor-driven fan are usually accommodated in a metal or bakelite housing with a suitable handle for directing the stream of air where required. Some makes include a switch which enables the heater to be switched off, so that cold air may be blown on to the hair, and other refinements include a speed control arrangement for the motor, so that the volume of air may be adjusted.

Warming plates, for keeping food hot, consist of an ornamental metal surface below which is situated a resistance-wire element, which is usually of a very low capacity, of the order of 100 W to 250 W. The element may be controlled by means of a three-heat switch, and a pilot lamp is sometimes provided to show that it is switched on. In one or two makes the resistance element is incorporated between sheets of heat-resisting glass, giving a pleasant and novel appearance to the device.

Electric blankets are made up of a series of resistance elements carefully wrapped in asbestos, and incorporated in a suitable fabric covering. A number of thermostats are also fitted, to take account of the temperature of any part of the blanket, and by switching off the circuit concerned prevent it from becoming dangerously hot. These blankets are not meant for use while the bed is actually occupied, but for previous airing and warming. They should never be folded in any way except that advised by the maker, as the elements might be disturbed or broken, and they are difficult to repair. Electric blankets should never be washed, they are generally provided with a cotton or linen outer covering which may be removed and washed if it becomes soiled.

Clothes-drying cabinets usually take the form of a steel or sheet asbestos cabinet, generally similar to a wardrobe, and having in the base a small heating element protected by a grill. Louvres are provided at the top of the cabinet to allow the heated air to rise up through the clothes, which are hung from racks, and then—having taken up the moisture—to escape at the top.

Although there are a large number of useful electrical heating devices employed in the home, such as coffee percolators, tea-makers, small immersion heaters and the like, they do not call for special mention from the electrical point of view. In practically every case a resistance element, which may or may not be controlled by a thermostat, is employed.

Electric Motors in the Home

The electric motor is used in the home in a number of ways, including the powering of vacuum cleaners, fans, food mixers, sewing machines and washing machines. It is also used in the refrigerator, which will be mentioned later.

The domestic vacuum cleaner takes two forms. There is first the cylinder type, in which a motor drives a suction fan drawing air through the pores of a cloth bag, which receives the dust-laden air

from a rubber flexible hose, at the end of which is the dusting tool. These are the simplest and least expensive types, and are very widely used. Electrically, the interest centres on the motor, which is usually of the series commutator type. The only maintenance likely to be required is the replacement or adjustment of the brushes which bear on the commutator. This can be quite easily carried out at home, providing the correct size of replacement brushes has been obtained. The commutator should be carefully cleaned with glass-paper (not emery cloth) and must be kept free from oil. The bearings of the motor may need a few drops of oil at long intervals.

The second type of vacuum cleaner employs the motor and the suction fan as before, but in addition a belt from the motor drives a rotary brush which "sweeps as it cleans". In this type of machine, the motor is slightly larger. A variant on the vacuum cleaner is the electric polishing machine in which the same type of motor is used to drive two rotating brushes for polishing all types of floor surface.

Electric fans are again of two kinds. Fixed ceiling fans, revolving at a relatively slow speed, may employ induction motors which do not need commutators and brush gear, as they are closely allied to the squirrel-cage three-phase motor mentioned on page 59. The shaded pole principle is employed to provide a rotating field. The only maintenance required by such motors, which are of a larger diameter than the normal fan motor, is the occasional replenishment of the oil in the bearings.

The pedestal type of fan, which may also be used on a fixed mount, usually employs a universal motor with a series commutator. It is generally similar to those used for vacuum cleaners, and again the brushes and the commutator are the only parts to need maintenance, except for occasional oiling of bearings.

Certain kinds of fan have an oscillating action so that the stream of air is continually driven in a fresh direction. This is achieved by means of a worm drive from the motor shaft, operating through a universal coupling on to a cam which drives the fan body from side to side. Other kinds of fan are situated in openings in windows or walls, with suitable louvres to prevent the ingress of rain or wind. They work by suction, to expel used air.

In large buildings, air-conditioning plants are often installed. The air is first taken from outside by means of a suction fan, then "washed" by being passed through a spray chamber and then dried by being passed over heaters, with strict control of the humidity to prevent undue dryness, and it may be further heated or cooled by being passed over pipes containing heater elements or refrigerant fluid. The electrical

equipment used for air-conditioning comprises motors to drive the fans and also the necessary heaters, with special control circuits to ensure controlled, automatic operation.

The food mixer found in many modern kitchens employs a small electric motor, usually of the series commutator type, to drive through reduction gearing a "head" to which a number of kitchen tools may be attached. For beating purposes, a gearing device may be arranged to provide an oscillating motion. Speed control is carried out by means of a variable resistance in series with the motor.

Electric drive for sewing machines is provided by means of a motor of about 1/150th h.p., which again is a series commutator type.

The electric washing machine comprises a tub in which is situated some form of agitator, while a heating element may also be provided. Many machines include a power-driven wringer.

The most commonly used washing-machine design incorporates a ¼-h.p. motor in the base, which drives a gear-box, incorporating a crank motion to give an oscillatory action to a paddle situated in the bottom of the bowl. The clothes are thus swirled round in the hot soapy water, to ensure that they are properly washed. Some designs use two agitators, one on each side of a rectangular tank. A shaft attached to the motor gear-box drives the wringer rollers through bevelled gearing.

Electric dish-washers take a number of forms, but usually employ a pump (driven by an electric motor) which forces high-pressure jets of hot water, impinging at various angles, on to the dishes to be washed. Some dish-washers include a timing control device, which is also occasionally employed on washing machines, so that an automatic time switch first switches on the heating element to ensure that the water is brought to the required temperature, then after a suitable time switches on the motor driving the pump. After a short period of high-pressure hot-water washing, an electrically operated valve changes over so that cold water from the mains passes through the pump and the jets then rinse the crockery, which is allowed to drain for a brief period and may then be dried by hot air by the switching on of a fan whose output passes over a heating element.

Electric Clocks

Electric clocks for domestic use are practically always of the synchronous type running on a.c. This means that the motor driving the hands is a synchronous motor whose speed is governed by the alternations in the supply system. When this system is employed the time-keeping qualities of the clock are related to the accuracy with

which the engineers in charge of the public electricity supply system govern the frequency. It should be emphasized that it is not the prime function of the Central Electricity Authority to "sell time": their purpose is to sell electrical energy, and although there are legal requirements that the frequency of the supply should be maintained within close limits, this is not always possible at times of heavy loading. At such times the frequency falls, and all electric clocks get slow. It is inadvisable to alter them, as in the majority of cases the control engineers will take steps during the night hours to speed up the clocks, until they are once more in accordance with Greenwich Mean Time.

The actual motor which drives the clock mechanism may take one of several forms. A truly synchronous motor would employ a small permanent magnet rotor, running between the poles of a stator of laminated iron on which a coil carrying the mains current is wound. However, in the interests of the cheapest possible construction, a form of motor is often employed in which a notching device is used. The coil is wound on a special iron former in the shape of a cylinder having a number of projecting teeth. The rotor, which drives the clock mechanism, consists of a flat disc also provided with a number of teeth, but these teeth do not coincide with the teeth on the stator. When the supply is switched on, and the clock is started, the rotor commences to revolve under the influence of the magnetic attraction between the teeth on the fixed and moving parts, and the flywheel effect carries it forward so that it continues to revolve, and keeps running at a synchronous speed. The consumption of electrical clocks is very small, and is usually of the order of 1 or 2 watts.

Electric clocks may be of the self-starting or non-self-starting types. The advantage of the latter is that if the supply is momentarily switched off, the clock will stop and will not start again, and will consequently not indicate an incorrect time. To start such clocks a small knob is provided which must be spun to start the rotor revolving.

Electric alarm clocks employ a mechanism for the setting and alarm feature which is generally similar to that in mechanical alarm clocks but the alarm may be sounded electrically, by the closing of a contact which switches the mains supply on to a small buzzer inside the clock.

An alternative type of electrical clock is the impulse clock. Here the supply of power may be obtained from any source, alternating current or direct current, while batteries are frequently used. The installation usually takes the form of a master clock and a number of slave dials. The master clock has a pendulum that can be adjusted to give extremely accurate time-keeping. Instead of being wound by some

mechanical means, the clock is kept going by means of an impulse from an electromagnet, given to the pendulum at intervals to maintain its oscillation. Every half-second, in most systems, the pendulum causes a contact to be made, which closes an electrical circuit from the supply to an escapement solenoid situated behind the face of the clock. This operates a ratchet, which moves the second, minute and hour hands on, in proper proportion, at half-second intervals. Any number of slave dials, each comprising an escapement solenoid and a gear mechanism, similar to that used behind the dial on the master clock, may be connected in parallel. This system is frequently used in large factories and buildings and enables the time-keeping system to be entirely independent of power failures.

Another piece of mechanism which is in many ways allied to the electric clock is the time switch. This consists of a time mechanism which may be a synchronous electric clock or a spring-driven clock, which is electrically wound. In the latter case, a lever incorporated in the clockwork mechanism moves over when the main spring becomes unwound, and causes an electrical contact to be made which closes the circuit of a very small mains-powered motor, which winds up the spring through worm gearing. The clock mechanism drives a dial or dials, which may be of a cam shape, and against which various contact mechanisms are arranged to bear. By setting the cams to various times of the day the circuits connected to the contacts may be arranged to open or close at predetermined times, as required. In many cases the time switch itself can only handle currents of the order of 3 or 4 amperes and consequently a relay or contactor is employed to control the main circuit, the time switch itself operating the contactor only. In this way a small time switch may be used, for example, to switch on the whole of the heating circuits of a large building, perhaps two hours before the staff arrive each morning.

Typical uses for time switches are to switch street lighting circuits off and on (in which case an astronomical dial may be used, taking into account the daily change of time of sunset and sunrise), the switching on and off of electric ovens when predetermined baking times have been completed, and the operation of devices which have been granted special electricity tariffs if used only during certain hours of the day.

Electric Razors

Electric razors employ a very small motor, of about 1/200th h.p., which runs at a very high speed and which operates through an

oscillating gear two sets of cutting blades, working one against the other. These shavers are often provided with two plug sockets, to take 110 or 240-volt circuits, and are practically always suitable for either alternating current or direct current operation. The change in voltage is achieved by a tapping on the coil of the motor. The consumption is very small, being of the order of 5 to 15 watts, and if need be razors can be operated from the type of battery known as the "high tension" battery for portable wireless sets.

Refrigerators

Refrigeration is a process of heat transfer. Basically, the object to be refrigerated is placed in a compartment which is insulated from the surrounding atmosphere, so that once the heat is removed new supplies cannot reach it by atmospheric conduction or by radiation. Inside this chamber is placed a cooling coil, which is simply a coil of piping through which a refrigerating medium—a gas or a fluid—may be made to flow to and from the actual refrigerating equipment, situated outside the chamber. This cooling coil is maintained at a temperature which is much lower than that of the objects placed within the chamber, and heat therefore flows to it from these objects and is not replaced. Heat, being a form of energy, cannot be "destroyed", it is simply transferred from one place to another. To effect this carrying-away process, energy is needed, and this is usually supplied electrically. In certain types of refrigerator, however, the energy input may take the form of the chemical energy in gas or paraffin, which is burned in the refrigerating unit.

There are two types of heat transfer cycle employed in commercial refrigeration. The first is the absorption type, and the second is known as the vapour compression type.

Both operate on the same basic principle, which involves the use of the latent heat of evaporation of a gas. When water is heated in a kettle or boiler the temperature increases steadily with the application of a given amount of heat. When the water is just about to boil the same heat will have to be applied for a considerable period without any change at all in temperature. This is because a change in state, from liquid to gas, requires a particular amount of extra energy in the form of heat, and this energy is known as the latent heat. When the steam is condensed back into water, the latent heat is given out again. Certain liquids have properties which make them especially suitable for use in the cooling coils of refrigerators. They must boil easily and must liquefy again at a suitable temperature and pressure. The gases

most commonly used are sulphur dioxide, various types of liquid known as freon, and—for large plants—ammonia. The freons are hydrocarbon and chlorine compounds.

The absorption type of refrigerator unit generally uses ammonia as the refrigerant fluid, and as the name implies it operates because water will absorb ammonia vapour. Liquid ammonia is placed in the cooling coil, and this coil communicates with a cylinder full of water. The water absorbs the ammonia vapour, and in doing so a partial vacuum is created. Liquids will boil at lower temperatures when the pressure above them is lowered and as the ammonia is absorbed by the water the pressure is gradually lowered until the ammonia boils, even at the low temperature existing in the cooling coil. In boiling, as mentioned above, the latent heat effect means that heat must be withdrawn from the surroundings to allow the boiling process to continue. This heat is drawn from the objects in the refrigerator cabinet, which are reduced in temperature (Fig. VIII, 10, left).

The water, which has now become saturated with ammonia, is then heated by some form of heater, which may be an electrical heating element, a gas flame, or a paraffin lamp. The ammonia vapour thus expelled from the water is then passed through a radiator, which is of course outside the refrigerator cabinet, and this cools it and sends the heat into the surrounding atmosphere. As the ammonia cools it gives out its latent heat, and becomes a liquid again and is returned to the cooling coil. By a suitable adjustment this process can be made to be continuous. In practice, there are a number of additional features and in the most commonly used refrigerator of the absorption type, hydrogen gas is used in the space between the cooling coil and the water absorption vessel, which has the effect of balancing out the pressure so that a steady cycle of heat transfer can take place without interruption. In certain absorption-type refrigerators a solid material such as calcium chloride is used in place of the water, and these units are known as the adsorption type, although the principle is the same.

The absorption-type refrigerator has the advantage that no moving parts are required, and if the whole system is made up in the form of a completely sealed unit it is extremely reliable in operation. It can, moreover, be operated from any heat source, as mentioned above. On the other hand, its efficiency is not as high as that of the compressor type.

The electrical equipment of an absorption-type refrigerator is limited to the heater and possibly to a lamp inside the cabinet which lights up when the door is open. This means that maintenance, from an electrical point of view, is confined to the replacement of a defective

heater or to the rectification of some slight defect in the door-operated lamp circuit. The refrigerator should always be earthed, and a three-pin plug should be used to connect it to the mains, care being taken to ensure that the earth wire is properly connected to the steel chassis. With the current switched off the replacement of the heating element by a new one is not difficult, as in most types the element either plugs in, or can be replaced by removing two screws. The lamp circuit contains only the lampholder (which may have become loose, or in

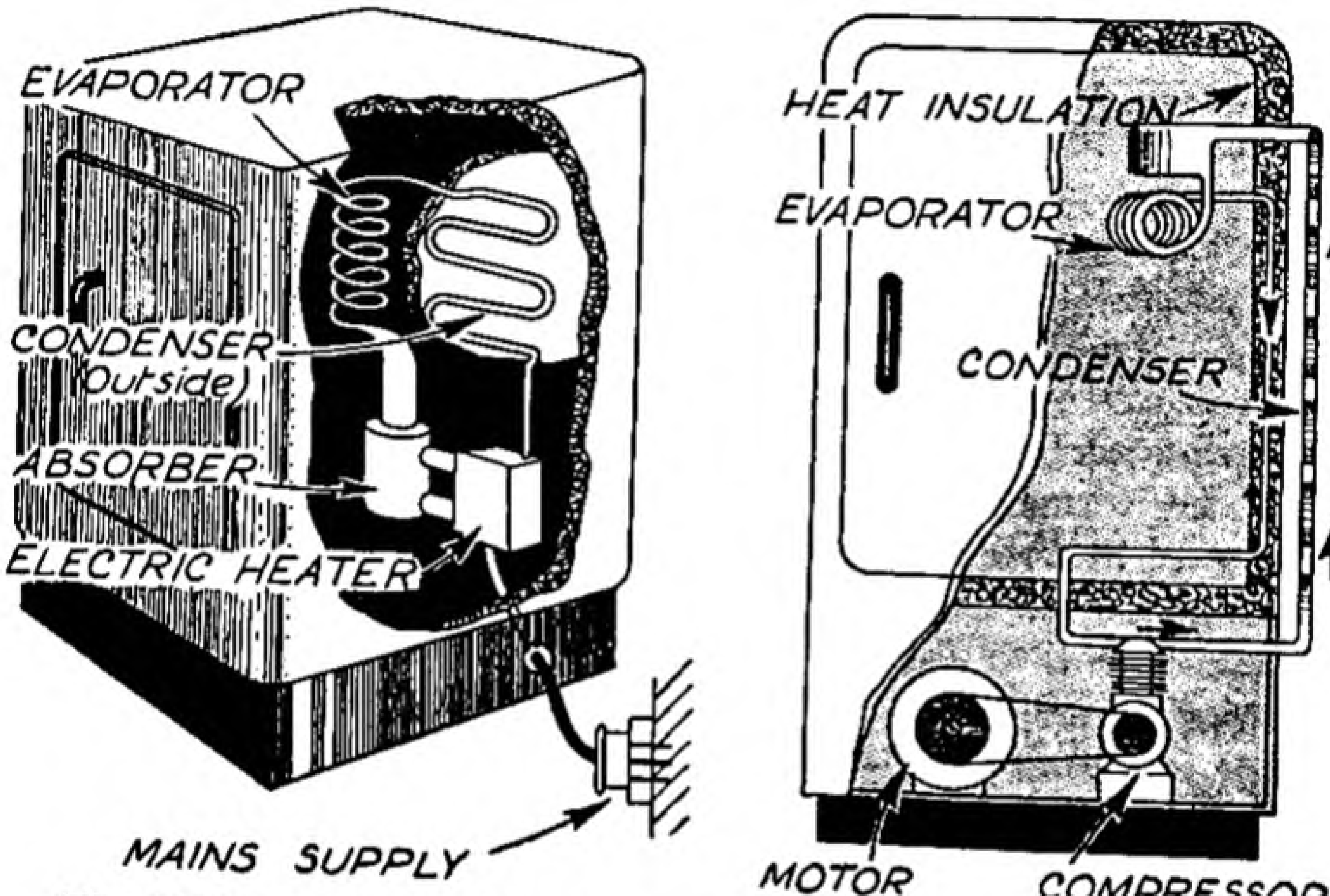


Fig. VIII, 10 (*left*).—The absorption type of refrigerator unit (*right*).—The vapour compression type

which the springs may be broken) and the door-operated switch. This switch can usually be removed, with the current switched off at the mains, by the removal of two screws on the face plate containing the plunger operated by the movement of the door.

The larger sizes of domestic refrigerator mainly employ the compression cycle. Here a compressor driven by an electric motor is used, and this is of the reciprocating type and may be compared to a single cylinder motor-cycle engine. On the suction side there is a connection to the cooling coil, or, as it is often known, the evaporator. The liquid, which is usually of the freon type, is thus subjected to a low pressure and this causes it to boil. Once again the latent heat phenomenon means that it must draw heat from its surroundings in boiling, and in doing so

it cools them down. The gas created by the boiling of the refrigerant liquid is drawn off and compressed in the compressor. Increase in pressure raises the boiling point, and it becomes a liquid again. This hot liquid is then taken to a condenser, which usually takes the form of a radiator mounted at the back of the refrigerator. Here the heat is dissipated to the atmosphere, as the gas gives out the latent heat it has absorbed in boiling; and as it cools it liquefies and passes on once again to the evaporator, and then the cycle continues. A fan is often provided on the motor shaft to blow air across the radiator and so assist in the cooling process (Fig. VIII, 10, right).

The compressor may be of the open type, in which case the electric motor drives the actual reciprocating compressor unit, either by a vee belt from a small pulley on the motor to a large pulley on the compressor, or the motor may be directly coupled to the end of the compressor shaft.

The alternative sealed unit is now very widely used for domestic refrigerators. In this case a special design of motor is employed which can be completely built in inside the crank-case (or its equivalent) of the compressor. In this way there are no joints or glands which may give rise to trouble; and providing proper attention has been paid to the design of the insulation of the motor—which is subjected to the chemical action of the refrigerant fluid—these units will run for an indefinite period without attention. There is in fact nothing that can be done to a sealed unit by way of maintenance, and the only possible action to be taken with a defective refrigerator of this type is to replace the complete unit.

In the case of the open type drive, there is the possibility of trouble arising at the gland on the shaft of the compressor where the refrigerant vapour may escape. This gland is sometimes provided with means for tightening, but anyone who is attempting to remedy a defect should remember that if the refrigerant has been leaking to any considerable extent there will be such a loss of fluid that the refrigerating cycle cannot function properly, and the unit will have to be taken back to the service depot where specialized equipment is used to recharge it. As an example of the difficulties that might be caused if the unit is improperly filled, a single drop of water in a gallon of refrigerating fluid will rapidly prevent the refrigerator from functioning, since the drop will freeze up and will clog the small-section pipes used in the refrigeration cycle.

In addition to the motor, the compressor-type refrigerator includes an electrical control device for ensuring that the temperature is set at the required level. This device takes the form of a thermostat which

has a temperature-sensitive element consisting of a bulb, containing a special fluid, which is situated near the cooling coil. This bulb is connected to a length of very fine capillary tubing, which terminates in a metallic bellows connected to a linkage operating a switch. The temperature changes in the evaporator cause the thermostat liquid to expand or contract, and in doing so it operates the bellows and consequently the switch. If the evaporator gets warmer than the desired setting the control element causes the motor to be switched on and the compressor operates. A knob is usually provided which can be adjusted to a number of settings, which are sometimes marked in actual temperatures and sometimes by numbers ranging from one to ten.

The contacts of the control unit may, on occasion, become slightly out of adjustment so that the motor does not switch on. There is a number of types of thermostat on the market and a general description is not feasible; but it is usually possible to inspect the contacts, with the current switched off, and see where the trouble lies. Frequently means of adjustment are provided, so that the contacts may be brought into correct operation again.

Troubles that may be encountered in both types of refrigerator are as follows. First, the absorption type may fail to freeze and this is likely to be due to a failure of the heating element. If, however, the heater can be seen to be in good order, then either the insulation of the cabinet has become defective so that heat from the atmosphere is reaching it too rapidly to be dissipated by the cooling coil, or else there is an internal defect such, for example, as a blocked pipe which can only be remedied by the makers or by a specially equipped service station.

In the case of the compressor type the unit may fail to start, in which case it should first be ascertained if the current is available either by checking that the internal light operates, or—if this is in order—by applying a suitable voltmeter to the terminals of the motor and then switching the current on, with the freezing control knob set to the highest point of freezing. Unless the contents of the cabinet are below this temperature the control thermostat should have its contacts closed and the motor should run. If there is no voltage at the motor, the contact of the control device should be checked. If these are in order voltage must reach the motor, and if it does not run the defect may arise from one of several causes.

First, the starting winding may be burnt out; or, if it is a capacitor start motor, the capacitor may be defective. Secondly, the main winding may be burnt out. In the first case, the motor will start if

rapidly spun by hand, but will not start itself. In the second case, it will not start at all. If it is certain that the capacitor is defective, a new capacitor can be obtained from the makers, and once it is fitted the motor should start without further trouble.

The majority of modern domestic appliances have radio and television interference suppressors fitted by the makers. Older appliances are not so equipped and may give rise to serious interference. The suppression of a motor-driven device can easily be effected by fitting a small capacitor, usually across the brushes of the motor. As this may give rise to a fault, with the possibility of blowing fuses, if the wrong size of capacitor is fitted, or it is not suitable for mains operation, this operation should be carried out by a professional electrician.

The Heat Pump

Imagine that the evaporator coil of a domestic refrigerator is removed from the cabinet, the pipework being extended. If the coil is buried in the earth outside, then the refrigerator will try to cool down the earth. It will, therefore, "pump" heat from the earth to the radiator at the back of its cabinet, and so, in theory, will warm the room.

In practice, the capacity of the domestic refrigerator is not sufficient to provide an appreciable amount of warmth, since it is only designed to cool the contents of a relatively small insulated cabinet. Moreover, the heat levels concerned are different from those associated with the heat pump, since the aim of the refrigerator designer is to cool a small quantity of warm substances over a fairly wide range of temperature, and to "pump" this heat out into the radiator at as low a temperature as possible. In the heat pump, on the other hand, the aim is to cool down—or try to cool down—the earth or the air by only a fraction of a degree, but to take out a large *quantity* of heat and to "pump" it (by refrigeration methods) so as to produce small quantities of very hot water, which can then be used for heating and domestic hot-water purposes.

The heat pump—looking very much like a refrigerator—is nowadays increasingly used in domestic installations. In one version, the heat pump stands in the larder and draws the heat out of the air in this room, thus creating a refrigerated larder, the heat being used to provide a considerable proportion of the domestic hot water requirements.

Suitability to the Supply

Nowadays, most domestic installations are supplied with alternating current, and when moving from place to place it is only necessary to ensure that the voltage is correct before commencing to use the

appliances in a new house. The standard voltage, as mentioned earlier, is 240 volts in Great Britain, and this standard is gradually being enforced in all parts of the country. A few districts, however, may be supplied at voltages widely different, such as 110 volts or 200 volts. Practically all domestic appliances suitable for alternating current will operate successfully on 220 volts to 240 volts without appreciable loss of efficiency, although lamps will give out less light if the voltage is low.

It is, of course, important that the correct voltage appliance should be always used. Where the voltage is different to a greater degree than about 10 volts to 20 volts from the figure mentioned on the appliance itself, it should not, in general, be used. If the new supply voltage is higher, heating elements—including the filaments of electric lamps—will have a shortened life and may burn out very rapidly. It is therefore desirable they should be replaced by elements of the correct voltage.

Radio and television sets usually have an adjusting switch or plug, giving a wide range of voltages, and this should be adjusted so that they correspond to the supply pressure. Motor-driven appliances are the least sensitive to voltage changes and 20 volts or so is not likely to affect their operation.

If the new supply is 110 volts, for example, and the user has a number of 240-volt appliances which he wishes to employ, the only solution is to purchase a transformer, to step up the voltage. The transformer must be of sufficient capacity for all the appliances to be used at once.

If direct current supplies are all that are available, lighting and heating appliances can generally be used, providing the voltage is correct. The switches with which they are equipped may not always be suitable for direct current, as the inductive effect when breaking a direct current circuit is more severe than in the case of alternating current. Professional advice should be sought on this point.

Radio and television sets must not be used on direct current circuits, unless they are specially designed for this type of current. Serious damage would be caused if they are employed on the wrong type of supply. Motor-driven domestic appliances are generally suitable for use on either kind of supply, because they are equipped as a general rule with universal-type motors. This does not apply to refrigerators. There may, however, be other cases where a motor suitable for alternating current only has been employed, and this can generally be ascertained if the motor is not equipped with brush gear and a commutator.

CHAPTER IX

RADIO AND TELEVISION

THE distinction between radio and television engineering and those branches of electrical engineering so far dealt with in this book is twofold. First, the majority of the circuits considered in radio and television operate with very high-frequency alternating currents; and secondly the heart of all radio and television sets is the electronic valve, in which—unlike all that has gone before (with the exception of the mercury arc rectifier)—current flows not through a solid metallic conductor but through the empty space inside an evacuated glass vessel. In this chapter, which will deal with the broad principles only of radio and television circuits, it is as well therefore to devote the first section to a brief reconsideration of the effect of high frequency.

In a 50 c/s electric circuit, if a coil wound on an iron core is introduced in series with the circuit, it will offer an impedance to the passage of the current which becomes greater as the frequency becomes higher. On the other hand if we introduce a capacitor into the circuit instead of the inductance, the impedance becomes less as the frequency increases. This may be understood quite easily if the *reductio ad absurdum* principle is applied: lower the frequency gradually and when it approaches zero the conditions become practically the same as in a direct current circuit. Direct current cannot flow through a capacitor at all, which consequently may be considered as offering an infinite impedance. On the other hand an induction coil offers impedance to the passage of direct current only at the moment of switching on, and after that the only effect it has on a steady d.c. circuit is due to the normal resistance of the wire of which the coil is made up. Now, if the direct current is changed into alternating current, and the frequency is gradually increased, the electromagnetic effect in the coil begins to increase and consequently the impedance increases. For the capacitor, however, the rapidity with which the current changes direction makes

the capacitor effect more pronounced—to put the matter unscientifically —and the impedance is less.

Imagine now a circuit consisting of an alternator and some current receiving device. If between these two pieces of apparatus a variable capacitor is introduced—one whose plates may be withdrawn one from the other to an infinite distance—as the distance between the plates increases, the capacitor will offer more impedance, and with a fixed frequency and generation voltage the current will become less. But if—as the capacitor plates are withdrawn—the frequency is raised, the increase in impedance caused by the change in physical dimensions of the capacitor will be compensated for by the increased frequency, as indicated in the previous paragraph (Fig. IX, 1).

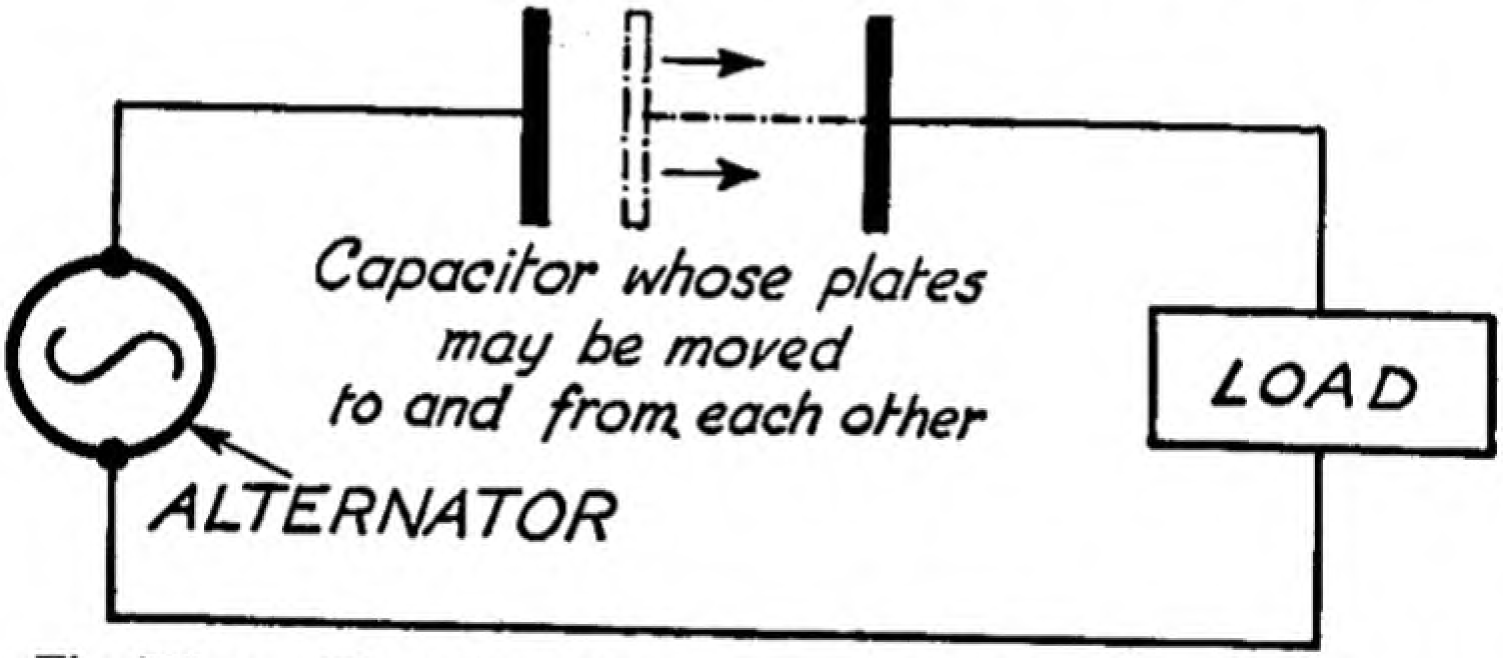


Fig. IX, 1.—The effect of a variable capacitor in an a.c. circuit

If the current receiving device is of a very sensitive nature it would be possible to envisage the completion of the circuit in this way over a distance perhaps of some miles, using a single wire for one side of the circuit and the air between the two plates of the capacitor as the other. If the earth is used as the return path instead of the wire (Fig. IX, 2) we have achieved an elementary "wireless" system, and by suitably switching the connection from the alternator to the nearby capacitor plate we could affect the current through the receiving instrument in such a way as to convey "intelligence". This might be done, for example, by keying on the Morse code principle.

(This elementary explanation is not to be regarded as strictly applicable to modern radio and television reception systems, but it serves to explain the necessity for high frequency for this purpose.) The term "high frequency" in this connection applies to frequencies of the order of 100,000 c/s per second up to as high as 30,000 million c/s per second, used for super-high-frequency short wave sets.

Wavelength and Frequency

The electromagnetic and electrostatic waves sent out from the aerial of the transmission station at these frequencies travel with the speed of light, which is 186,000 miles per second. Thus the wavelength may be calculated for any frequency since, with a given speed, it would take a large number of very short waves or a smaller number of very long waves to span a given distance in a given time. The wavelength of the B.B.C.'s Light Programme transmitter is 1,500 metres and this corresponds to a frequency of 200,000 c/s per second. The short waves used in connection with television lie between 41 million c/s per

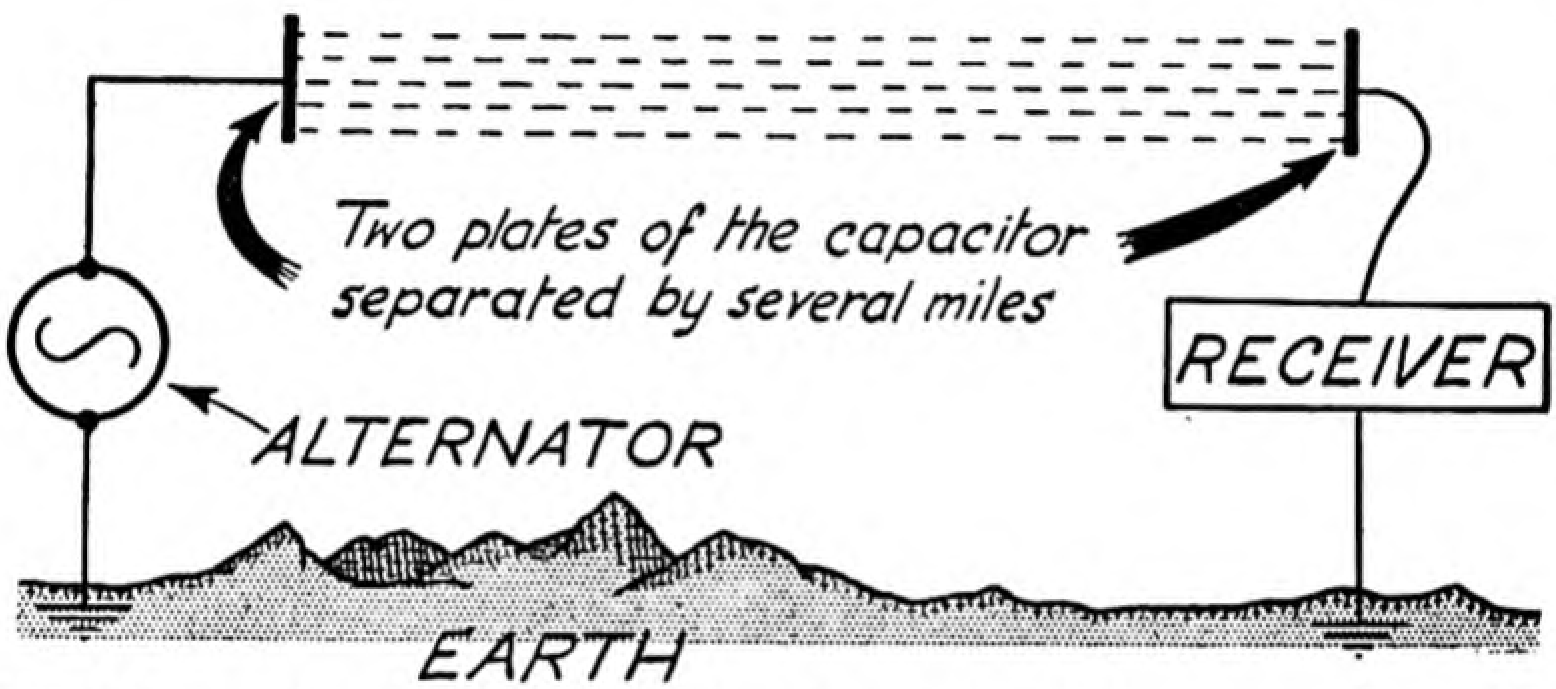


Fig. IX, 2.—An analogy to a radio circuit, involving a capacitor with plates removed a very great distance from each other

second and 68 million c/s per second, that is to say with wavelengths of between about $7\frac{1}{2}$ metres and 5 metres.

Ionized Layers

The earth is surrounded by ionized layers which act as reflectors of wireless waves. If this were not so, long-distance reception would be difficult, as much of the energy would fly off into outer space. However, these layers as well as assisting radio transmission also tend to hinder it, since they vary in height and other qualities and thus the reflection does not always take place in the same way. In consequence certain wavelengths or frequencies are better adapted for radio transmission in one direction at one time of day or year than others. Long waves (low frequencies) require more power in the aerial for a given distance of transmission, and this is understandable by reference to our original analogy of the capacitor with its plates withdrawn from each other over a long distance. The higher the frequency the less the impedance,

and conversely the lower the frequency the greater the impedance and the more power needed.

Broadly speaking, high power long wave stations are used for commercial communication and radio telegraphy over very great distances; medium wave stations such as those which radiate the B.B.C. Home and Light programmes are used for coverage of an area which might perhaps be considered as half the area of the British Isles; and very high-frequency short wave systems are employed for low power short distance communication such as aircraft-to-airport services, police cars and television. The coverage of very high-frequency waves may be increased by increasing the power of the transmitter, but there are certain physical limits which prevent this process being carried far. Broadcasting, in Great Britain, is gradually changing towards using a large number of very high-frequency stations. The reflection of very short waves from the ionized layers in the upper atmosphere often gives rise to freak reception distances when conditions are favourable, as instanced by the occasional reception of B.B.C. television programmes in South Africa.

The second main distinguishing feature between radio technique and other aspects of electrical engineering is the use of the valve.

The Radio Valve

It was in 1890 that Dr. Fleming began experiments on the emission of electrons from the carbon filament of what was then the normal electric lamp. He found that electrons were given off whenever the filament was heated; and by placing a metal cylinder round the filament, and giving it a positive potential in relation to the filament circuit, the electrons could be attracted to the filament and a flow of current, through the exhausted glass vessel could take place. The valve was further developed by Dr. Lee de Forest and others, and its amazing properties soon came to be realized. It acts in three ways: as an oscillator, an amplifier and a rectifier.

The modern electric valve (or tube as it is known in America) consists of a glass tube mounted on a plastic base and containing three basic elements and possibly a number of others. The basic elements are the emitter or cathode section; the anode to which the electrons are attracted; and some form of grid or grids in between, to control the flow of electrons.

The cathode may be of two kinds. In some valves, mainly those for battery use, the small coil of wire that is heated by the passage of current is itself the emitter of electrons, while in other types of valves

(known as the indirectly heated type) the heater filament may be separate from the cathode, which consists of a specially treated plate or cylinder, surrounding the heater and from which emission takes place.

The simple two-electrode valve, known as the diode, has certain uses in radio circuits but its function is confined to that of rectification. Current can pass only from the cathode to the anode, in the direction of the stream of electrons emitted from the cathode and attracted by the anode. If a grid is inserted in the valve between the cathode and the anode (Fig. IX, 3) and if a voltage is applied to this grid, it may be used to accelerate the electron flow, by adding a greater positive "pull" to the anode, or it may retard the flow by being negative and consequently reducing the attraction. Thus the grid acts like a tap, and its presence enables the valve to carry out its most important function of amplification. The grid needs no current but only a voltage, and thus a change of grid voltage or potential does not involve the provision of power. A minute change of voltage on the grid may produce a very large change in current flow in the valve. Thus a very feeble signal reaching the valve may be made to control a very large power output. A small child turning a tap with one finger can control a powerful jet of water; and this analogy conveys the action of the valve as an amplifier.

The triode valve may also be provided with other grids for special purposes, and a number of valve assemblies may be made up within the same glass tube; but all of them basically operate on the principle set out above.

We have seen elsewhere how the valve acts as an oscillator.

The important part of the oscillator circuit, from the radio point of view, is the tuning arrangement whereby the oscillation is kept at a fixed frequency. We may perhaps recapitulate the principles on which resonant circuits operate. A capacitor, which is usually variable, is connected in parallel with an induction coil. If we imagine that no resistance is present in such a circuit, the current flow through it would be a completely *leading* current in the capacitor leg and a completely *lagging* current in the inductance leg. If the value of these two currents were so adjusted, by varying the capacitor, that they were equal in magnitude, they would exactly balance out and the combination would in effect form an infinite impedance, through which no useful current at all could be made to flow (Fig. IX, 4). This condition would only apply at a particular frequency, since the impedance of the two legs varies with the frequency; and since these variations are not alike, at any other frequency than the one selected the two currents

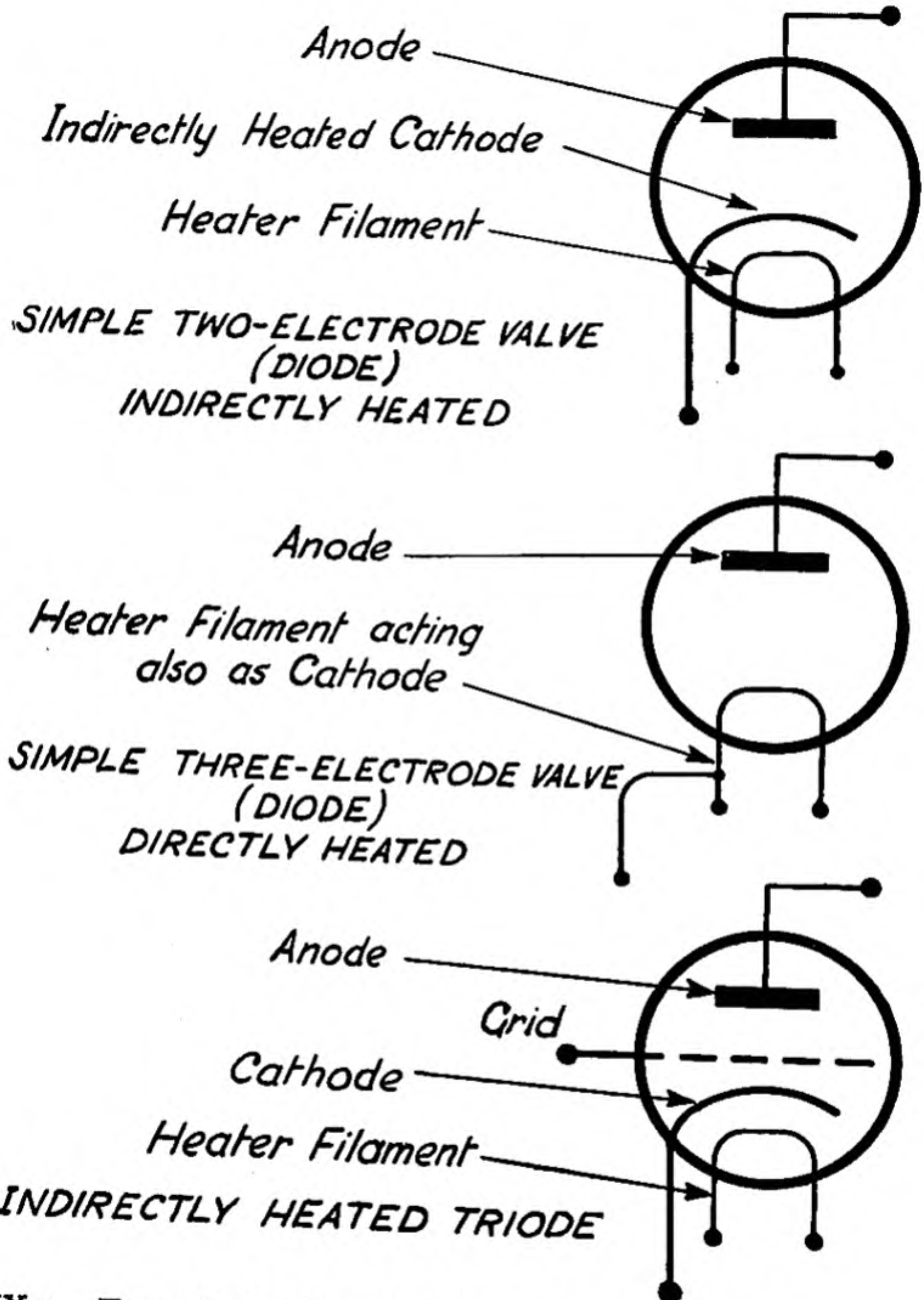


Fig. IX, 3.—Types of valve, indicating the symbols used to describe each type

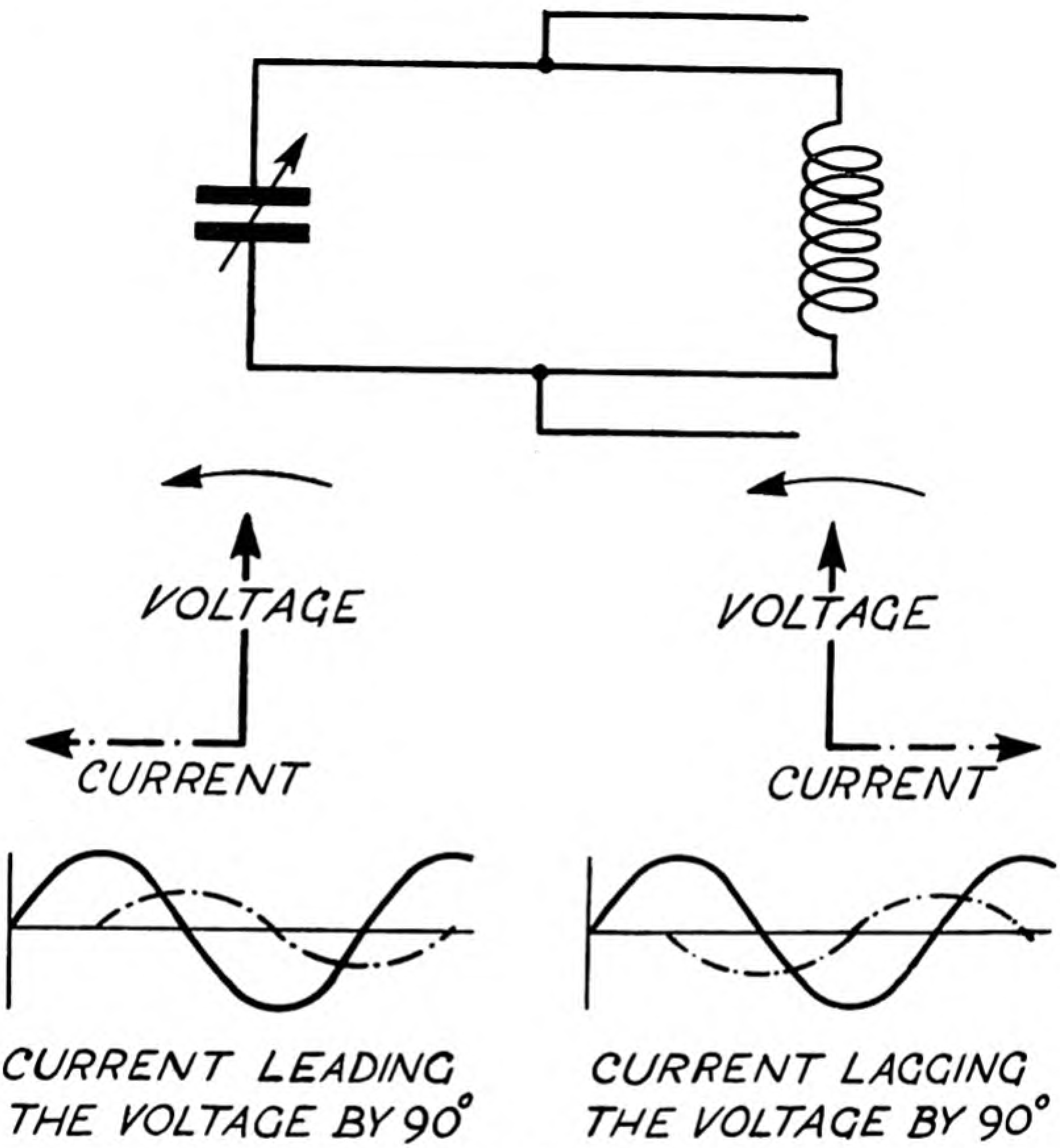


Fig. IX, 4.—Diagram to illustrate the principle of the resonant circuit

would not balance out. Such a balanced circuit is stated to be "tuned" to a particular frequency, and forms the basis of all radio circuits, both those at the transmitter and at the receiver.

If an electromagnetic coupling is set up between the inductance leg of such a circuit and a second coil nearby which is coupled in to the anode circuit of a triode valve (i.e. if the fluxes in the two coils can inter-act), and further if the resonant circuit is connected to the grid of the same valve, the elements of oscillating circuits are set up. A "kick" of energy from the anode circuit starts off an oscillation in the resonant circuit, which imparts a voltage kick to the grid, which in turn cuts off or diminishes the anode current (Fig. IX, 5).

As the oscillatory current in the resonant circuit reverses as the

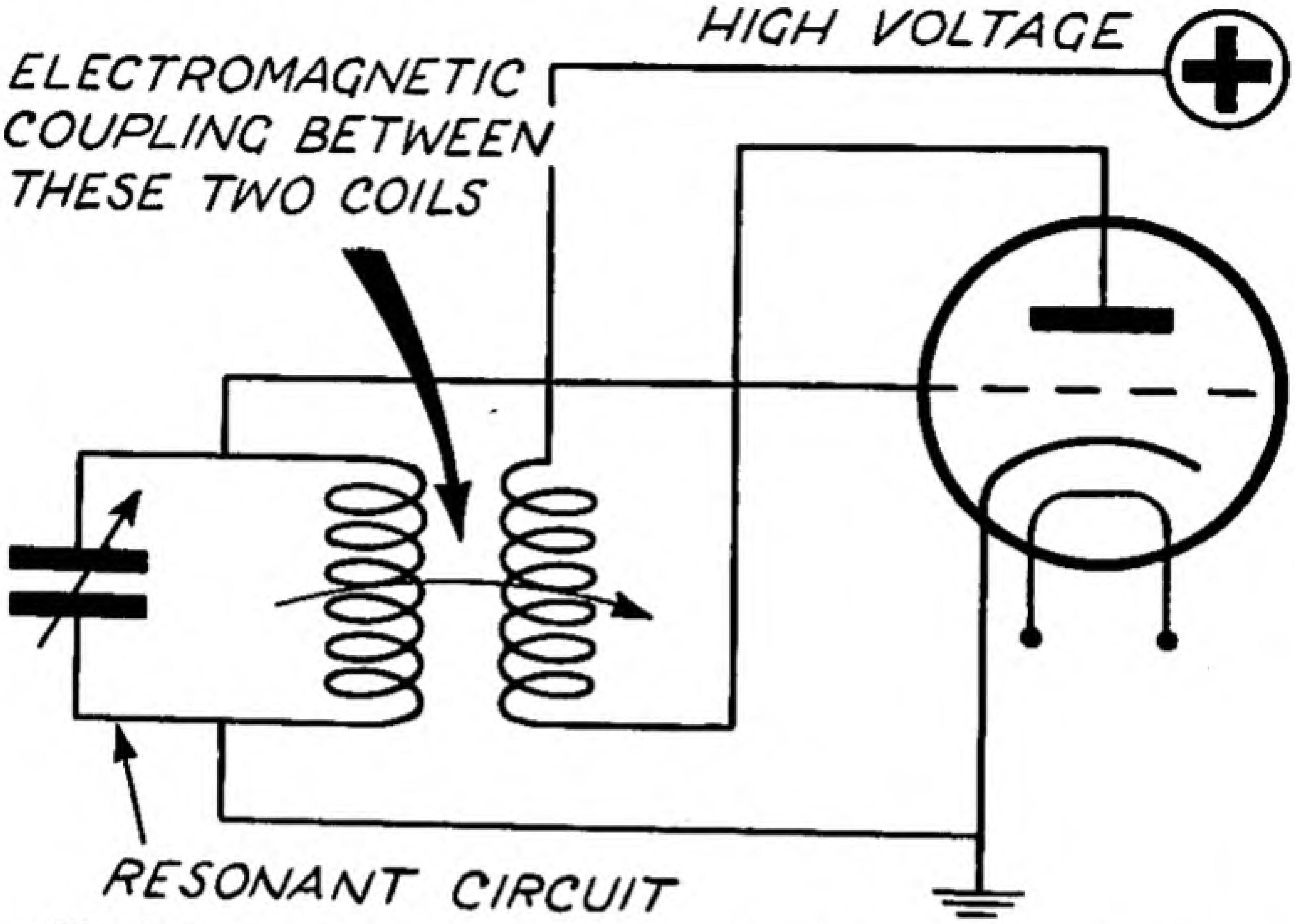


Fig. IX, 5.—The resonant circuit applied to a valve oscillator

capacitor discharges a kick of voltage of the opposite sign will be applied to the grid, which will start off another pulse in the anode circuit. This in turn will allow some energy to be communicated from the anode circuit, where the high voltage power is applied, to the grid circuit made up of the two resonant legs. Thus the oscillatory process will continue, and will set up an alternating current in the anode circuit which is of the frequency set by the resonant circuit connected to the grid.

The transmitting of radio signals may be carried out in a number of ways and in the early days the bursts of energy were sent up the aerial simply by "keying" or switching the power supplied by an oscillating valve to the aerial. In this way bursts of high-frequency energy were emitted, in accordance with the Morse code, and could be received by suitable apparatus.

Wave Modulation

Before long, however, the system known as modulation took its place, and this is now universally used for all types of radio communication. Basically, the transmitting station emits a continuous high-frequency impulse, known as the carrier wave, which is modulated

to carry the intelligence being transmitted. We shall see a little later how this intelligence is separated at the receiver from the carrier wave, but to explain how it is incorporated with the carrier wave, we might first consider how a sound wave is translated into electrical impulses in a broadcasting studio.

Several types of microphone are used to receive the sounds, but a typical instrument would comprise a fine ribbon of flexible aluminium situated between the poles of a powerful magnet, equipped with a coil on each pole. The sound waves emanating from, say, the playing of a piano, take the form of pressure waves in air, which cause anything interposed on their path to vibrate. The ribbon in the microphone vibrates in sympathy with the air-pressure waves, and if we imagine that the pianist strikes the A to which an orchestra is normally tuned, vibrations at the rate of 440 pressure waves per second are set up, which result, when the microphone ribbon is set into vibration, in a change at the equivalent rate in the flux cutting the ribbon. This in turn means that the coils on the magnet are affected by a changing flux, and an electromotive force which varies exactly in accordance with the original pressure waves is thus set up. In this way the musical sounds have been converted into electrical impulses, and are generally known as audio-frequency waves, to distinguish them from the much higher-frequency radio waves.

If these impulses are conveyed to amplifier valves, to make them greater in magnitude, they are now ready for being applied to the carrier wave. If the amplified audio-frequency is made to affect the grid of a valve through which the high-frequency wave is passing as it is being amplified, the amplitude, or height of the wave peaks of the carrier current (the high-frequency wave), will be affected in accordance with the audio-frequency waves. Fig. IX, 6, shows the audio-frequency wave carried, so to speak, "on the back" of the carrier wave. This is called "amplitude modulation".

A second method of imposing the audio-frequency impulses on the carrier wave, known as frequency modulation (F.M.), is being increasingly used. Here, the amplitude of the carrier wave is always the same, but its frequency varies according to the variations in the audio-frequency impulses. This system is suitable only for use on very short waves (very high frequencies) and therefore is usually limited in range: but it has the advantage that it almost entirely eliminates interference. Interference of any kind cannot alter the *frequency* of the signal, which is the deciding factor in F.M.: whereas in ordinary amplitude-modulated broadcasting, the interference *can* affect the amplitude of the wave, and so cause unwanted noise in the receiver.

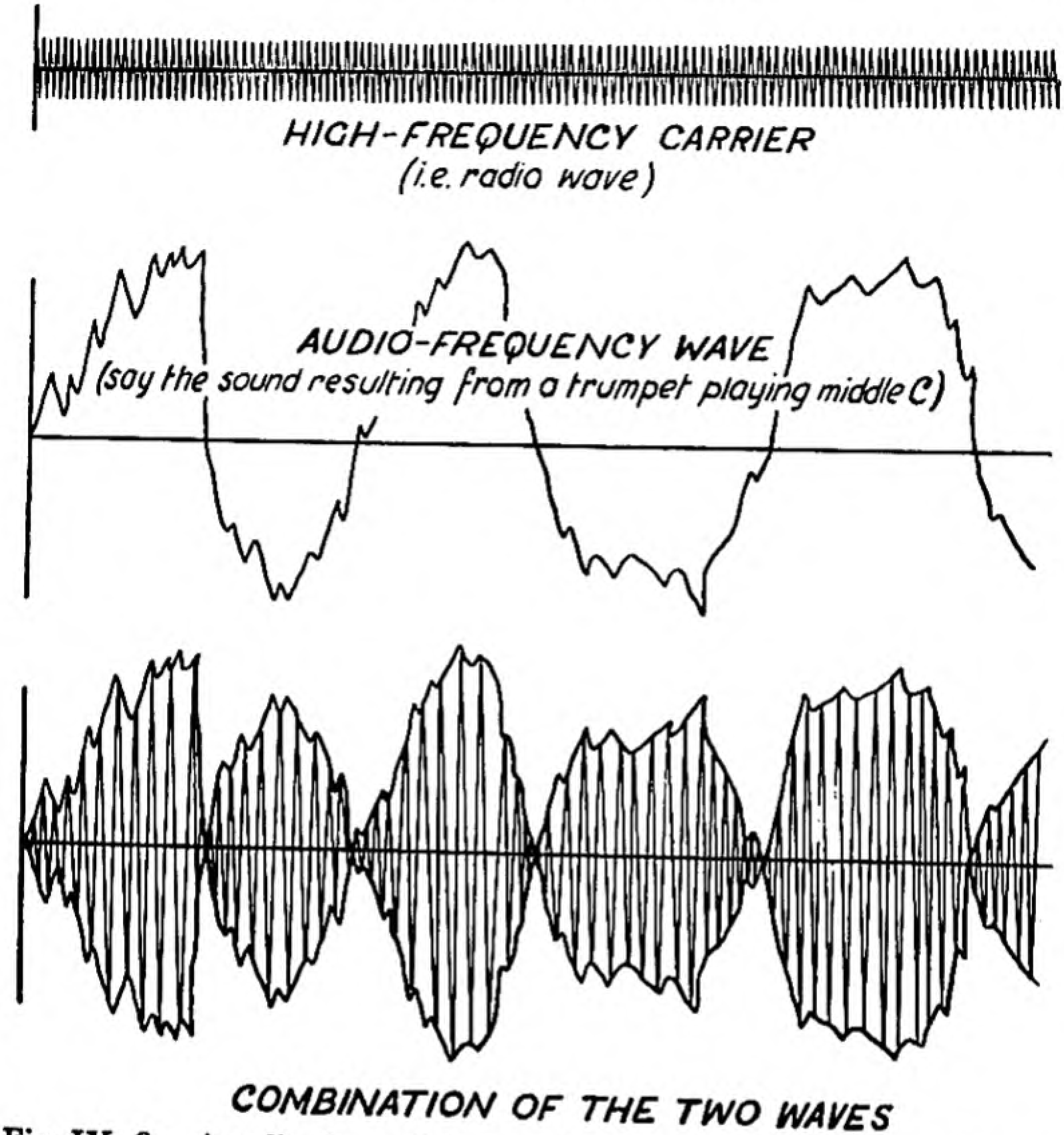


Fig. IX, 6.—Amplitude modulation of a carrier wave by a sound wave

We have now discussed very briefly the elements of which a transmitter is made up. Transmitters with perhaps 500 kW of power being radiated from the aerial comprise massive buildings in which are situated the incoming power supply arrangements and the large rectifiers needed to provide the high voltages for the transmitting valves; as much as 20,000 volts may be needed for this purpose. Standby diesel engines are often installed in case of power failure. The transmitter hall consists of a number of cubicles, each containing valves and their attendant tuned circuits, comprising the various stages of amplification through which the incoming signal from the transmitter is carried before it is powerful enough to be applied to the carrier wave.

It is extremely important that the frequencies of broadcasting stations should be absolutely constant. Ordinary tuned circuits of the type mentioned above would not be sufficiently stable for this purpose, and the piezo-electric effect is therefore employed. This effect arises from the fact that certain types of quartz crystal will vibrate at a fixed frequency when a voltage is applied, and will hold this frequency absolutely constant, provided the temperature is kept constant. Such a device is known as the crystal oscillator, and the crystal is used electrically as the "capacitor leg" of the basic resonant circuit which provides the carrier-wave frequency. The crystal is kept in an oven whose temperature is controlled very accurately, and it forms the heart of the oscillating valve assembly, which produces the carrier wave.

The transmitting aerial or antenna may take many forms. It may be required to carry the intelligence in a fixed direction only, as in communication circuits for radio telephony and the like. Radio waves can be beamed exactly in the same way as light waves, and a motor-car headlamp provides an analogy for the beam system used in radio. A slight alteration of the position of the bulb in the reflector will alter very considerably the direction in which the main beam is thrown. (There will, however, always be a certain distribution of light along directions outside the main beam.) Arrays of vertical and horizontal wires will be seen near communications transmitting stations, and these form both antennae and reflectors, and are carefully positioned to direct as much as possible of the beams of radio waves in the required direction.

The receiving end of a radio circuit comprises first an antenna or aerial which acts in effect as the "remote" plate of the variable capacitor we mentioned earlier. It picks up the energy radiated by the aerial, and along its length there is generated a very small electromotive force. Although before the days of the valve there existed various methods by which this voltage could be detected, the enormous amplification possible by the use of the triode valve enables extremely feeble signals to be picked up and made intelligible. Less than a tenth of a millionth of a volt (which is a common figure for the voltage produced in an aerial by a transmitter, say, 100 miles away) is ample for satisfactory reception.

The alternating current voltage brought to the receiver by the aerial consists of the modulated carrier wave. The very high frequency used for the carrier has served its purpose and must be got rid of. This process is known as detection. First, however, the receiver must be tuned to the correct wavelength, as a number of broadcasting transmission stations may be sending out impulses at the same time, all of

which will induce currents in the receiving aerial. The tuned circuit is again used for this purpose, and it will be recalled that when it is tuned to a particular frequency, it offers the highest possible impedance to currents of that frequency. If such a circuit is introduced between the aerial and earth, the highest possible voltage will be built up across it when it is tuned to the frequency of the transmitter concerned, and thus the maximum amount of energy, free from extraneous energy impulses from other transmitters, can be passed on to the remainder of the receiver.

The amplitude-modulated carrier wave, as we have seen, consists of a high-frequency wave whose amplitude, both above and below the zero line, varies from instant to instant in accordance with the audio-frequency modulation. The a.f. energy so transmitted over a given single cycle of the high-frequency wave is zero, since as much energy is sent in one direction as the other. If, however, the bottom half of the wave can be cut off, the energy over a given period of time is now equivalent to the amplitude of the upper halves of the waves, and if these can be smoothed out, the result will be an electrical voltage equivalent to the original audio-frequency voltage produced at the transmitting station microphone (Fig. IX, 7).

As we have seen the valve acts as a rectifier, and a rectifier cuts off the negative half-waves. Various kinds of rectifier can also be used, and radio technique is to some extent returning to the early days of the cat's whisker and crystal—a rudimentary form of rectifier—since highly developed crystal rectifiers are now taking the place of valves for many duties in radio receivers. Crystal amplifiers are also being introduced, both these and the crystal rectifier being known as transistors.

In the ordinary radio receiver there may first be an amplifier which boosts the incoming signal, and this will be followed by a detector valve stage, where the bottom half of the incoming carrier wave is cut off. The detector valve may be a simple diode, which serves no other purpose than rectification, or detection as it is called in this connection, or it may be a triode valve so arranged that it also carries out a degree of amplification. In the anode circuit is an inductance which serves to smooth out the high-frequency impulses making up the audio-frequency wave, and the resulting current is then passed to one or more stages of amplification before it emerges as sound waves, from the loudspeaker (Fig. IX, 8).

Most modern receivers use the superheterodyne principle of tuning. The basis of this method is the "beat note" heard when two nearby piano keys are struck together, with the damper pedal held in

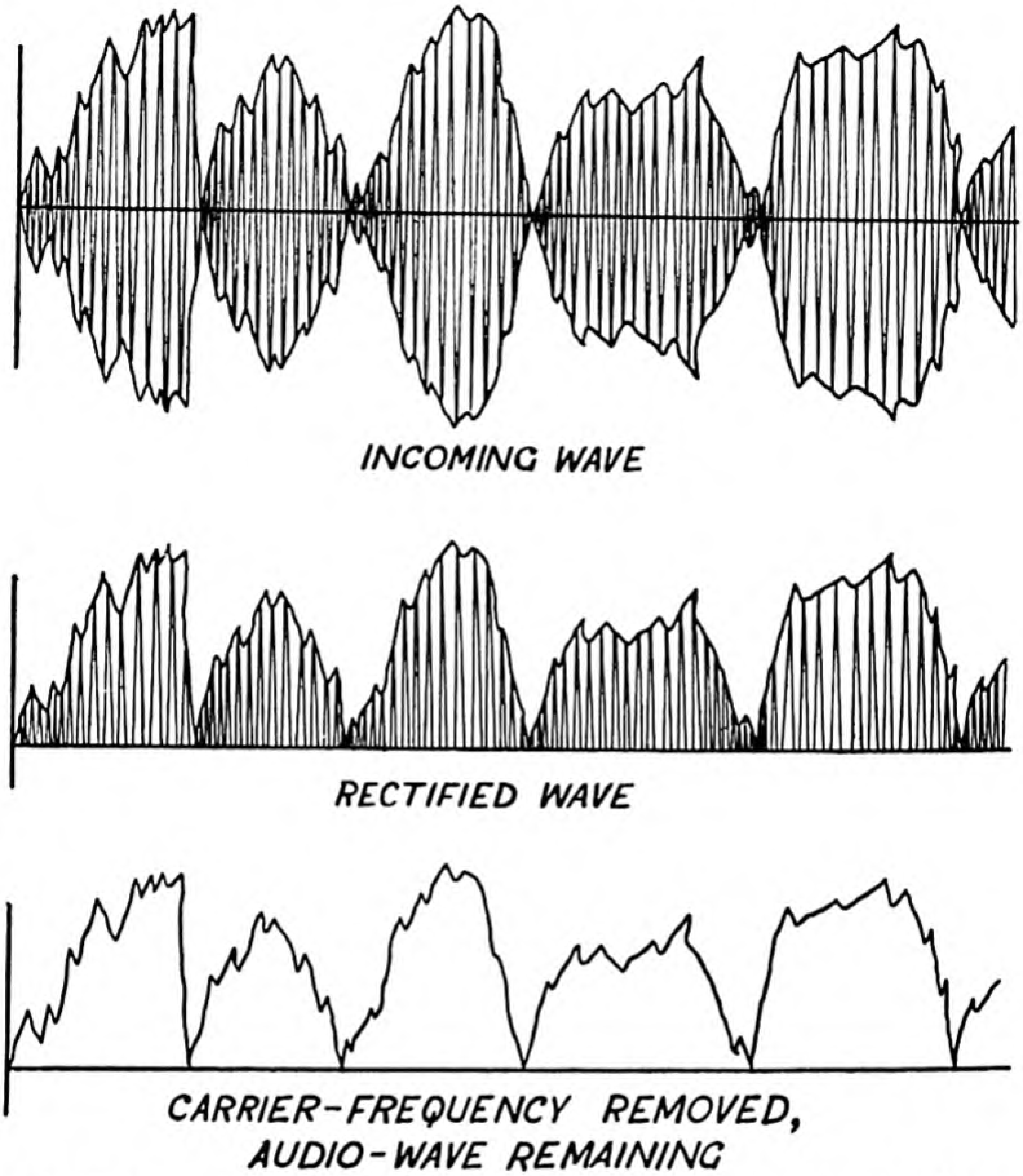
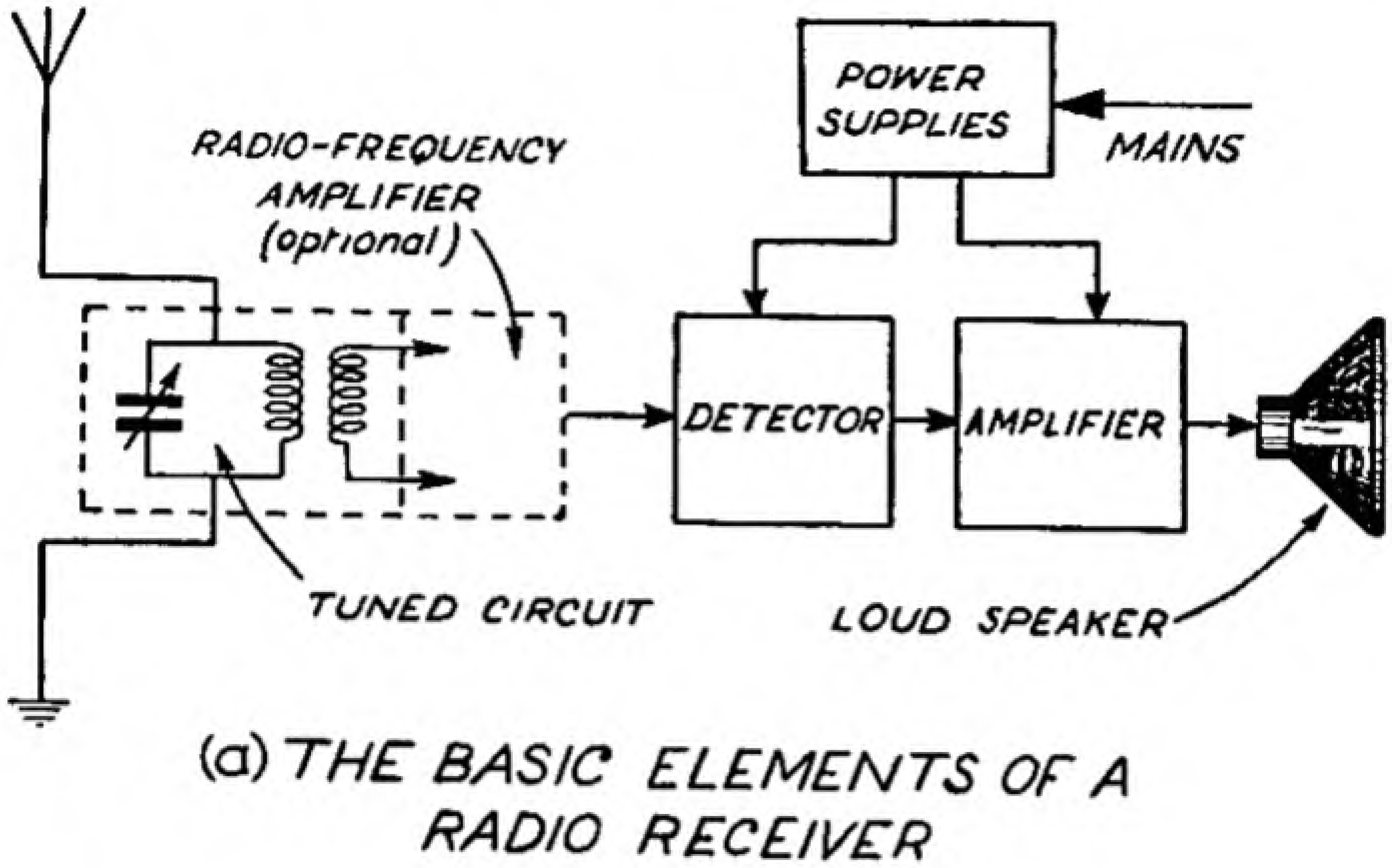


Fig. IX, 7.—The principle of the "detection" or rectification of an amplitude-modulated incoming radio signal

the "off" position. The two notes reinforce each other at regular intervals, forming another note, much lower in pitch; in fact, having a pitch which corresponds to the difference in pitch between the two original pitches. It is helpful to consider two men walking together, one of whom takes rather shorter steps than the other; every so often the two men will place their left feet on the ground at exactly the same instant.

The high frequencies used in broadcasting and communication work are such that it is not always easy to provide tuned circuits giving the sharpness of tuning necessary when a number of stations are



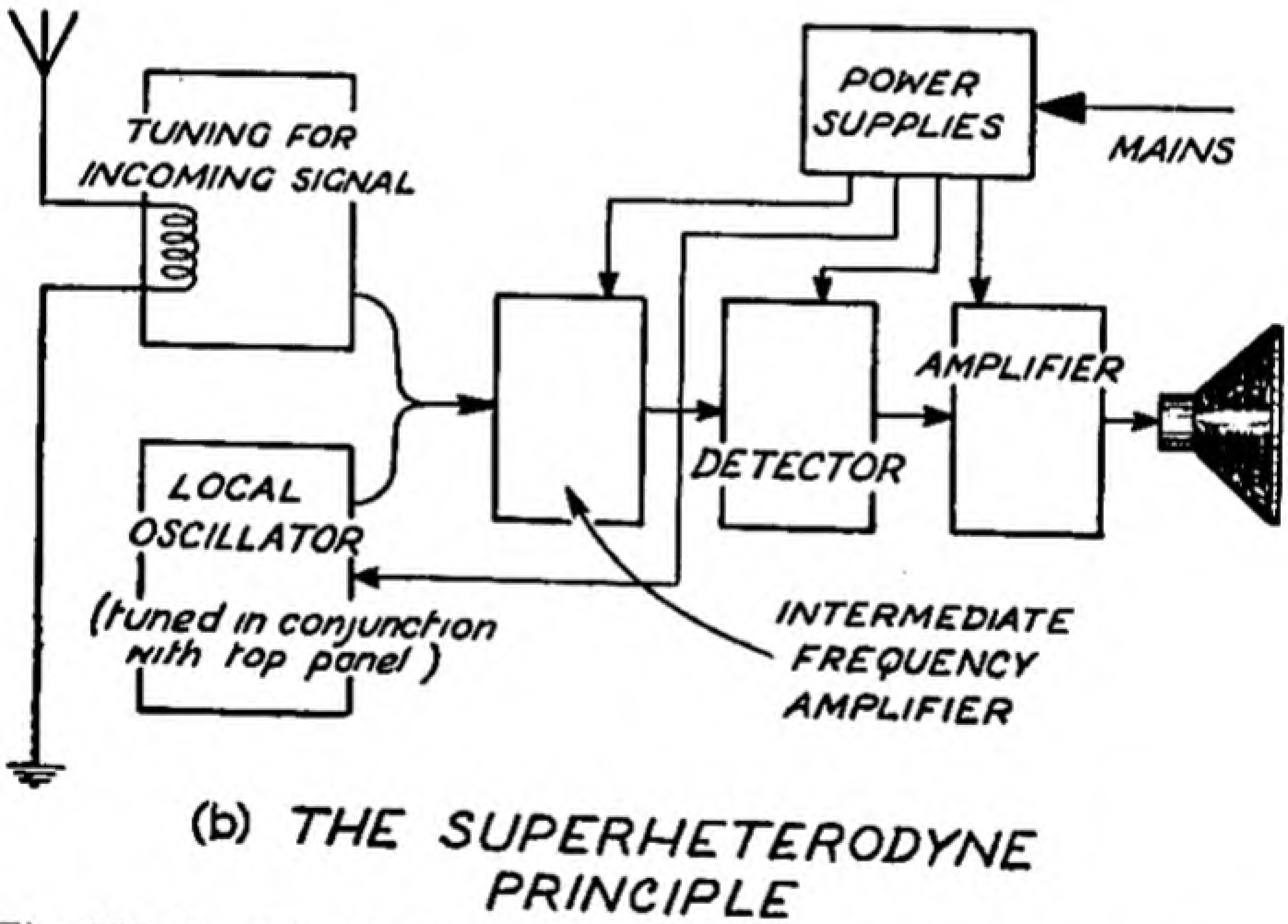


Fig. IX, 8.—The basic elements of (a) a simple radio receiver; and (b) the superheterodyne principle of reception

operating on nearby wavelengths or frequencies. The lower the frequency the easier it is to provide satisfactory tuning circuits. This is taken advantage of in the superheterodyne receiver by providing a small "local transmitting station", or oscillator, within the receiver itself, of a frequency separated by some few kilocycles from that of the incoming wavelength to which it is desired to tune. If a frequency of

3,000,000 cycles per second is coming in on the carrier wave, and the local oscillator is tuned so that it provides a frequency of, say, 3,455,000 cycles per second, a "beat note" or heterodyne frequency will be set up, between these two, of 455,000 cycles per second. This heterodyne frequency will automatically be modulated by the audio-frequency signal, which is obviously a much lower frequency and one which can conveniently be handled both by the tuning circuits and by the later stages or amplification. As this "beat note" can only be set up by one particular degree of difference between the incoming signal and the local oscillator, the intermediate frequency, as it is called, is fixed, and all the circuits that occur in the later stages of the receiver have fixed tuning arrangements, which may be set up with great accuracy in the manufacturer's works.

The remaining stages of a receiver consist of the power pack and the loudspeaker. To supply the anode voltage of the valves about 250 volts are needed, and this is usually obtained by means of a rectifying valve with smoothing chokes and capacitors to render the direct current output as free from "ripple" as possible, since ripple causes "mains hum" in the loudspeaker. In receivers for a.c. only, a transformer is provided to step up the mains voltage to the required figure—which is somewhat higher than normal mains pressure owing to the losses in the rectifier needed for the high voltage supplies. The transformer also provides, through the medium of a third winding, the power required, at about 6·3 v for the heater circuits of the valves. In "a.c. or d.c." sets the mains voltage is rectified without the use of a transformer, and the heater circuits are connected in series directly to the mains.

The loudspeaker comprises a permanent magnet between the poles of which there is situated a coil of fine wire carrying the output current from the last valve. The coil is attached to a cone, flexibly clamped at its edges, so that it can vibrate as the coil moves in the magnetic field due to the variations in its current caused by the audio-frequency waves.

TELEVISION

A television system consists basically of a scanning equipment at the transmitter end, a radio (or wire) link and a receiver. Of these three the radio link employs, broadly speaking, the same equipment as that for sound radio transmission, although the frequencies employed are considerably higher. For this latter reason the radius of coverage

of television stations is less than that of sound broadcasting stations of the same power.

To understand how television transmission is carried out, first consider a photographic print. If this print had to be transmitted by some electrical method, a spot of light might be directed on to the print and might traverse it in some regular fashion, say, along horizontal lines from left to right, and the dark parts of the photograph would reflect very little light on to a receiver device, while the light parts would reflect a great deal of light. If the receiver device took the form of some type of apparatus which would convert light intensity into electric voltage impulses, there would be a series of regular impulses corresponding to the shades of light and dark in the picture.

In the case of the photograph, which is obviously an unchanging image, there would be no particular speed at which this scanning operation would have to be carried out. If the object to be scanned, however, consisted of a moving figure, the scanning of the whole field of view would obviously have to be carried out sufficiently rapidly for the eye, at the final receiver, to be unaware of the mechanics of the scanning mechanism. In the normal cinema picture, the eye is in fact presented with twenty-four pictures each second, with an infinitesimal pause in between. The faculty of retentivity enables the eye to retain the image of one picture long enough to bridge the gap between that picture and the next, and so the illusion of continuous motion is secured. Thus the scanning of a television camera must be so arranged that the whole field of vision is completely scanned at least twenty-four times a second. In practice varying systems use a different number of frames per second, but they are of this order: and the number of "lines" (the number of traverses across the picture which the scanning spot performs as it covers a complete survey of the field of view) may also vary. It is 405 lines in the case of the B.B.C. transmissions, while as many as 900 lines are used on Continental systems to give much finer detail.

The heart of the television camera is the electron image tube where the light rays, focused by means of ordinary optical lenses, change the light rays from the scanning spot into electrical impulses. The optical image produced by the lens is focused on a plate in which there are many million tiny globules of a specially treated form of silver which have the special property of becoming electrically charged to a degree that varies with the strength of illumination to which they are subjected. This image is scanned by a beam of electrons, which carries away the electrical potential generated on each globule, and this potential is amplified and passed on to the transmitter (Fig. IX, 9).

The means whereby the scanning takes place can best be explained by reference to the receiver end, where a generally similar electrical arrangement exists.

The cathode ray tube, which forms the television receiver screen, consists of a glass bottle having a broad end, which is usually flat, and which contains near the neck a filament, a grid and a cylindrical anode. When the filament is heated and a high positive potential is

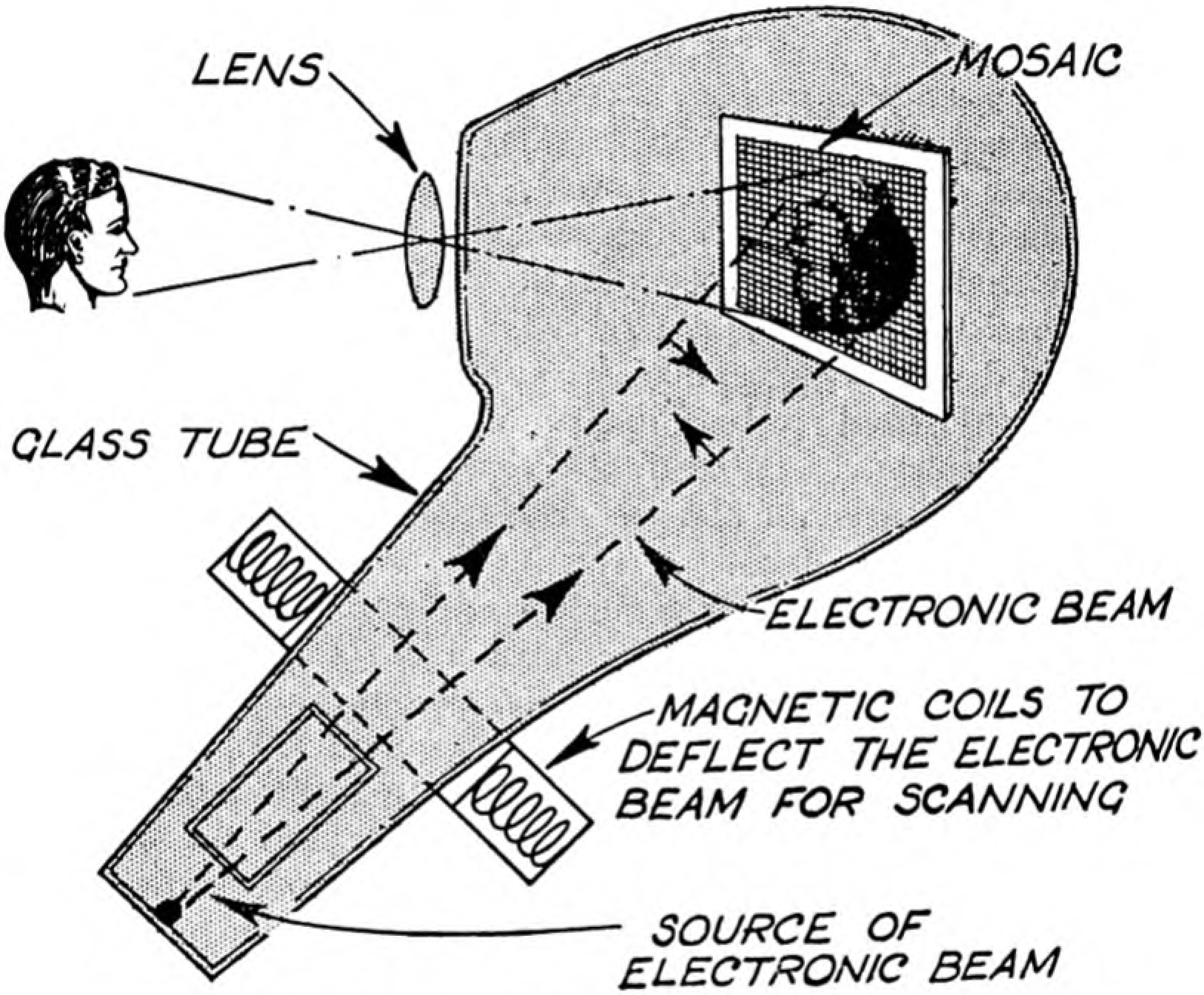


Fig. IX, 9.—The principle of the television camera tube

applied to the anode, a stream of electrons is projected through the hole in the anode, this stream being established and attracted by the positive potential, in the same way as in the ordinary triode valve. This beam of electrons forms, as we saw in Chapter I, the basis of the electric current. It is subject to the same laws as those which cause an electric motor to operate. A magnetic field when suitably disposed in relation to the beam of electrons will cause it to move in the appropriate direction, as given by the left-hand rule. If electromagnets are situated on the neck of the bottle in such a way that one of them will move the beam from side to side, and the other will move it up and

down, the beam can obviously be made to sweep across any desired area of the end of the bottle (Fig. IX, 10). The impulses causing these sweeping or scanning movements are provided by what are known as time base circuits, which include valves of a type which will emit timed impulses, and these impulses are arranged to affect the coils of the electromagnets. This arrangement is used in the television camera for the beam of electrons to scan the photoelectric plate.

The bottom of the bottle, in the case of the cathode ray tube, is covered with a fluorescent powder, as in the ordinary fluorescent

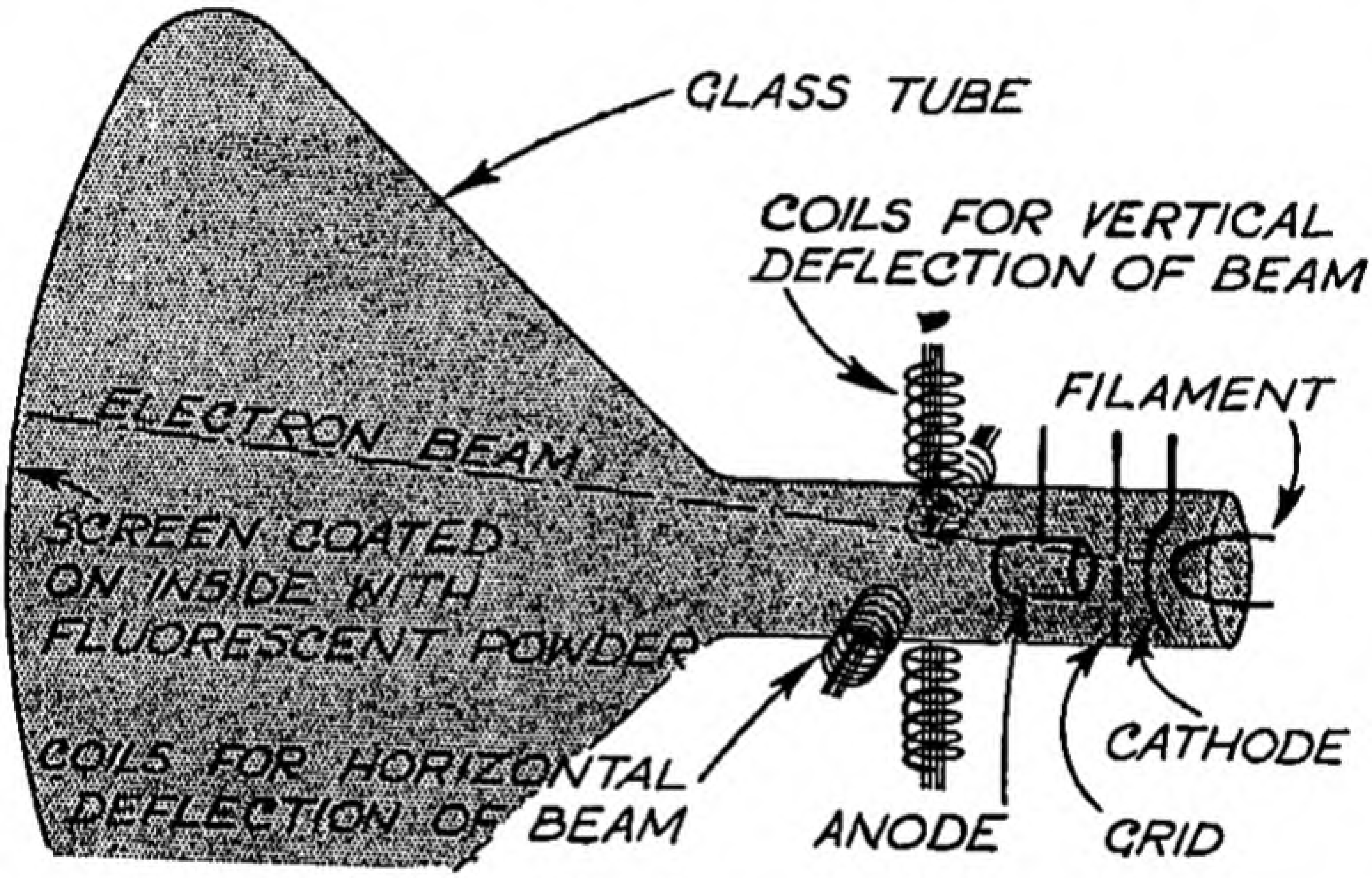


Fig. IX, 10.—The television receiver tube

lamp. This glows to a degree corresponding to the intensity with which any particular particle is bombarded by the electron screen, this intensity being varied by means of the variation of voltage on the grid.

We are now in a position to consider the whole television link. We have first a camera in which a lens projects the field of view on to a photoelectric plate, in much the same way as an ordinary camera projects an image on a ground glass screen. We then have a scanning beam which picks off from this plate the electrical potentials acquired by each one of the millions of particles it contains. The beam moves in an orderly sequence across the field of view back to the beginning and across again, making 405 lines down the height of the picture and carrying out the whole operation twenty-five times a second. This produces electrical impulses which are obviously themselves of a very

high frequency (unlike the audio impulses from sound waves, which reach only about 12,000 c/s per second) and so must have a very high-frequency carrier for them to modulate. The frequencies actually employed are the order of 4,000,000 c/s per second.

These impulses are then transmitted over a radio link and are received on a superheterodyne receiver and passed to a cathode ray tube. There they affect the intensity of the beam of electrons which is being traversed across the fluorescent screen, at the same speed and in step with the beam in the original camera. This synchronism is achieved by superimposing a special synchronizing signal on the transmitting impulses, to hold the two beams in step. As a consequence of this arrangement, the fluorescent screen glows, as each element of it is attacked by the beam, to an intensity corresponding with the light intensity on the original picture at that particular point. The very slight afterglow which occurs with fluorescent materials, together with the retentivity of image possessed by the human eye, enables the illusion of a continuous picture to be presented.

RADAR

Television and radar are closely related. The very short waves used for television begin to approach the wavelength of light and this is demonstrated by the fact that television reception to some extent follows an optical path and cannot penetrate obstacles which would prevent the passage of a beam of light. When even shorter waves are used the similarity between the beam of light and the radio wave path becomes even greater.

If a very sharply focused spot lamp was held in one hand, and a focusing mirror in the other, both pointing backwards, it would be possible to arrange the two of them so that the beam from the torch struck some object and was reflected exactly in the mirror (Fig. IX, 11). The object would be behind the observer, but by finding out the angles at which he had to hold the mirror and the torch, he could calculate the distance of the object away from him by ordinary range-finding methods. If moving objects were being searched for, he could tell whether an object were present or not at a given distance, by noticing whether the beam of the torch was reflected back.

In the basic radar equipment, very sharply focused beams of waves are emitted in pulses from sharply focused aerials. A receiver aerial, which also takes the form of a reflector suitable for the wave-length being used, receives back any reflections which may come from an object hit by the outgoing waves. The time taken for the wave to

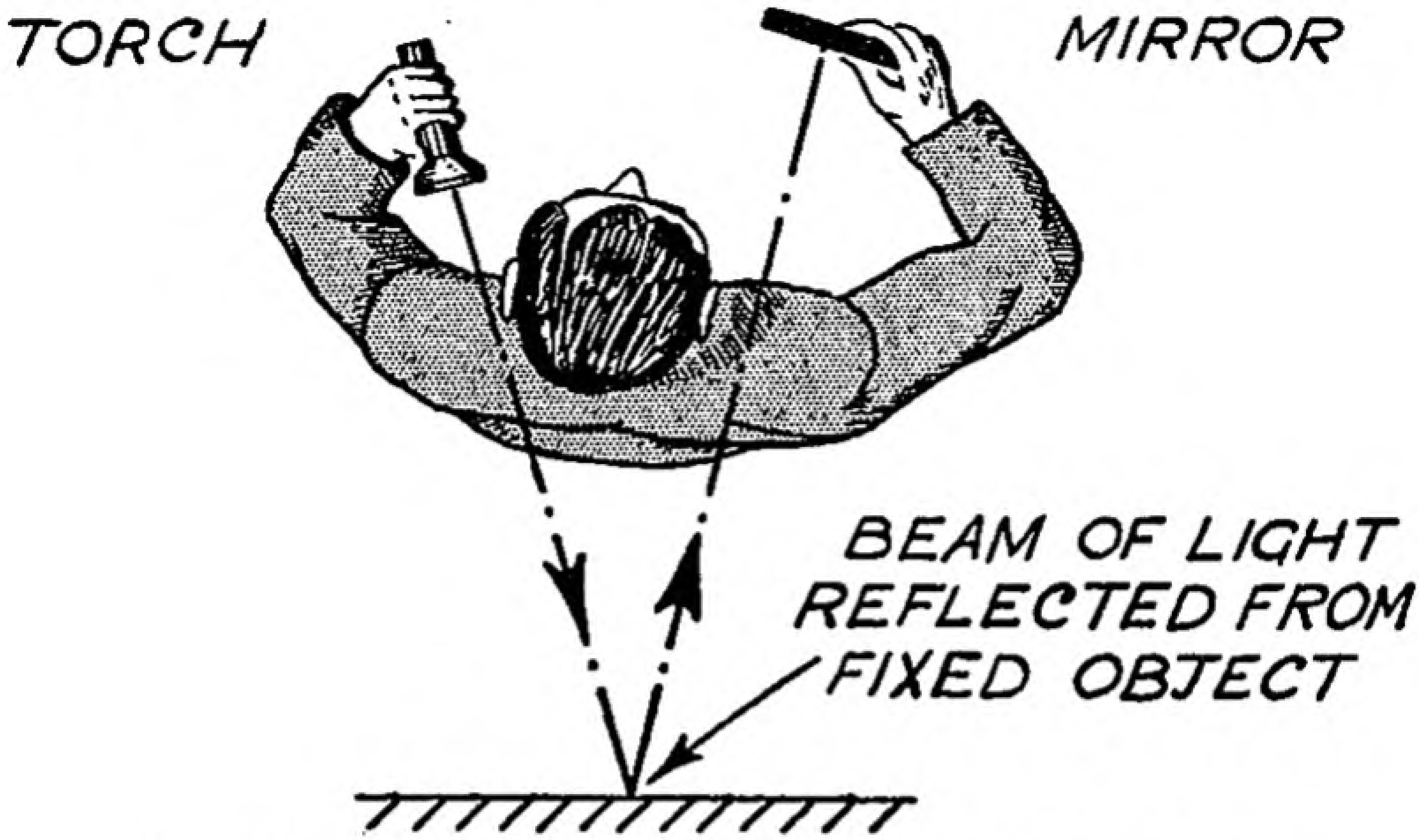


Fig. IX, 11.—Diagram illustrating the principle of radar

traverse the outward path plus the return path from the object can be measured, and can give an indication of the distance of the object from the radar receiver. This time is, of course, a matter of millionths of a second, but the use of the cathode ray tube enables it to be, in effect, slowed down by using a suitable time base.

The transmitting and receiving aerial may often be one and the same thing and may revolve, continuously scanning the horizon. A spot of light on a cathode ray tube is arranged so that instead of scanning horizontally across the tube, as in a television set, it acts in the form of a continuously revolving radius between the centre and the circumference. The electric circuits are so arranged that if the beam meets an object and is reflected back, it causes a glow to appear on the cathode ray tube at the corresponding point on the horizon, so that the position of objects can be marked out, in relation to the compass points, by the observer.

The cathode ray tube is also used in a large number of devices which come under the general heading of navigational aids for aircraft, and which employ variants of the radar principle.

CHAPTER X

IN THE WORKSHOP

UNTIL recent times, the sole function of electricity in the workshop was to provide power and light; now electrical energy is used to heat the workshop itself and to provide energy for a very wide variety of processes; to condition the atmosphere, to provide remote control and indication, and for many functions of accountancy in the workshop office.

The motors used in workshops may be divided under two headings. First, there are the main drives for the fixed machinery; and secondly, the motors used for portable tools.

MOTORS AND SPEED CONTROL

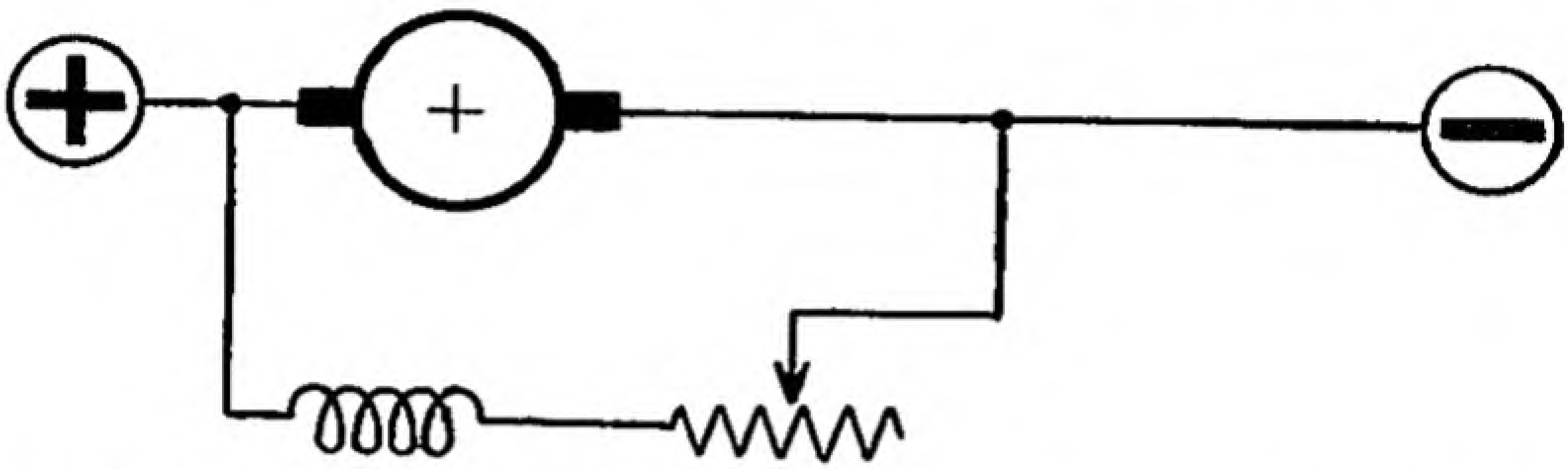
Main drive motors may again be divided in several ways, but the principal distinction to be drawn is between fixed speed and variable speed motors. If a d.c. supply is available, the provision of variable speed does not present much difficulty, within certain speed limits. It is only necessary to instal a field or armature resistance, or both, of the type which allows for continuous operation at any particular setting (Fig. X, 1).

It must be realized, however, that a motor designed for a particular torque at a particular speed will not necessarily give its full output at another speed; the speed-torque curve, which can be obtained from the makers, should be consulted. For small d.c. motors, below about 1 h.p., speed regulation may be obtained simply by using a series resistance, as the energy wasted in heat in the resistance coils may not be worth consideration. In any case, such motors are often of the series wound type in which case the series resistance is the only practicable method (whereas the larger motors are usually compound wound, with a shunt and series winding).

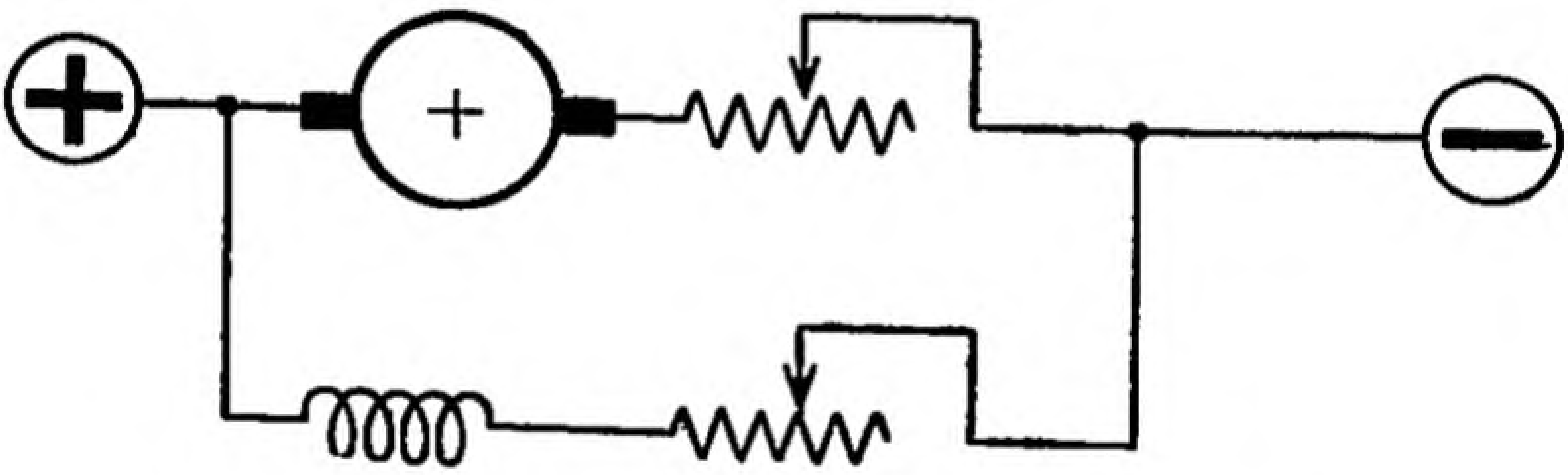
Speed variation with a.c. motors is not always easy to achieve,

though a variable choke, or inductance, is sometimes used in place of the resistance.

The speed of the larger a.c. motors is linked closely with the frequency of the supply and the number of pole-pairs into which the winding is divided. For single-phase motors, speed control offers many difficulties. One method, which provides only two speeds, consists in



SHUNT FIELD RESISTANCE FOR SPEED REGULATION



FIELD AND ARMATURE RESISTANCES FOR SPEED REGULATION

Fig. X, 1.—Methods of speed control for d.c. motors

employing a stator with a type of winding which can be made either two-pole or four-pole, the change-over being effected by means of a switch. In this way two speeds, one twice the other, can be obtained.

For ratings above about 1 h.p., most motors are of the three-phase type. Fixed speed motors are usually of the squirrel-cage design, in which there is no connection to the rotor. Inserting a resistance in each of the three phases of the line will not have the effect of varying the speed but will only weaken the torque. Pole changing is the only possible method of altering the speed of a squirrel-cage motor, but as a rule motors with wound rotors are used where speed variation is

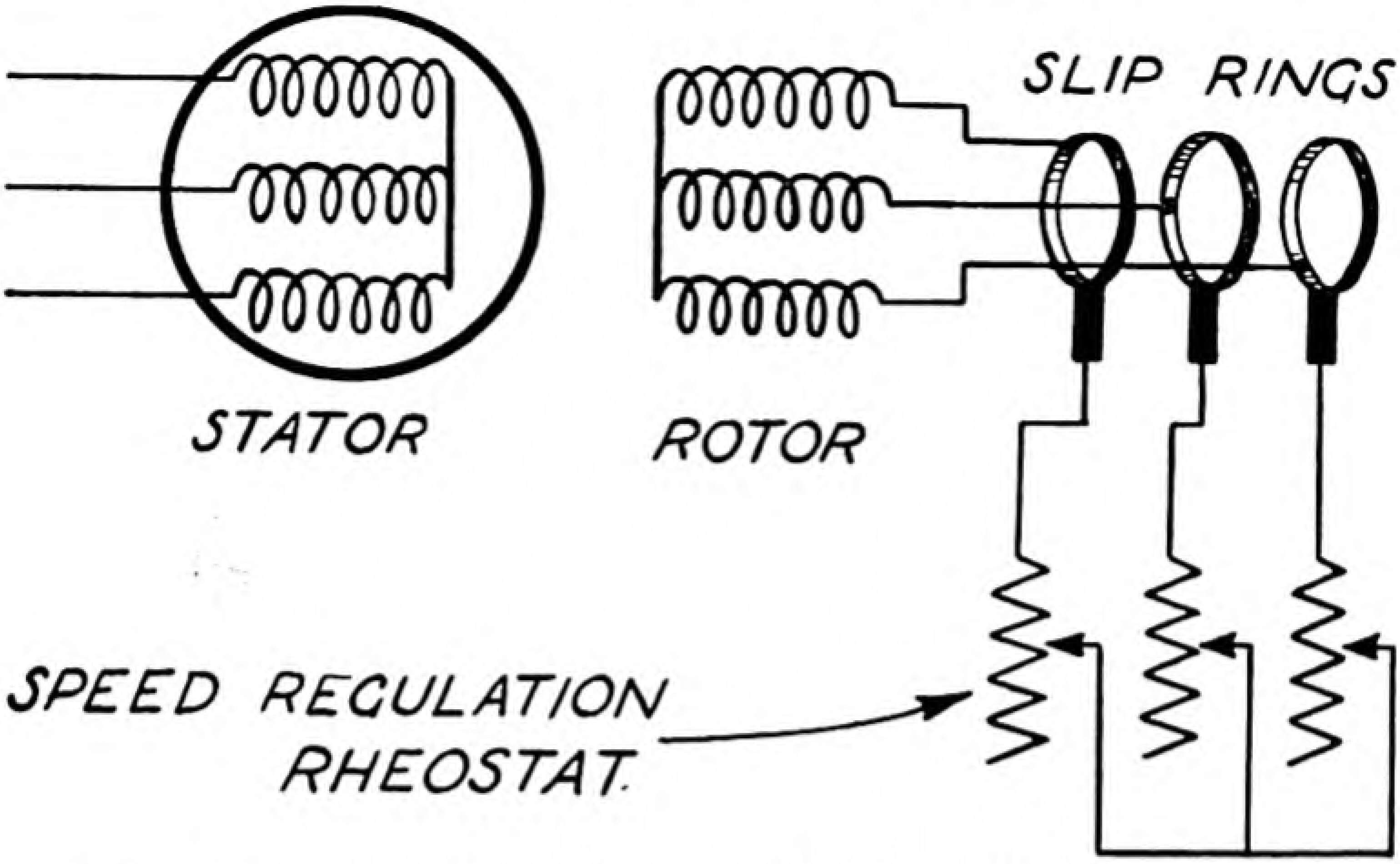


Fig. X, 2.—Speed control method for a.c. slip ring motors

needed. These motors have a set of three slip rings and the ends of the rotor windings are connected, *via* the slip rings, to a variable resistance (Fig. X, 2). This resistance has three equal limbs, which are varied together. In this way a wide range of speed control may be obtained, but the energy so wasted has to be balanced, economically, against the advantages gained by the use of variable speed.

For the very largest sizes of motor, the Ward-Leonard or Ilgner systems are employed when speed control is necessary (Fig. X, 3). In both these systems the mains supply is brought to an a.c. induction motor operating at a fixed speed. This motor drives one or more d.c. generators which supply energy to the main motor, which is obviously also of the direct current type. By varying the excitation of the fields on the generator and on the main motor, this system allows for the exact control of the speed over the whole range from zero to full speed, and for instant reversing. The control gear, which is often electronic in nature, includes the provision of pilot exciters which are capable of delicate control of voltage, so that the voltage and current supplied to the field windings of the generator and of the main motor are capable of smooth variation and, if required, reversal. Braking can also be carried out very smoothly.

The Ilgner system employs, in addition to the foregoing, a large flywheel, which enables the main motor—perhaps of 20,000 h.p.—to overcome peak loads without drawing heavy peaks of current from the supply. When, for example, a rolling mill receives a heavy ingot, the power required momentarily is very large, and a drive without a

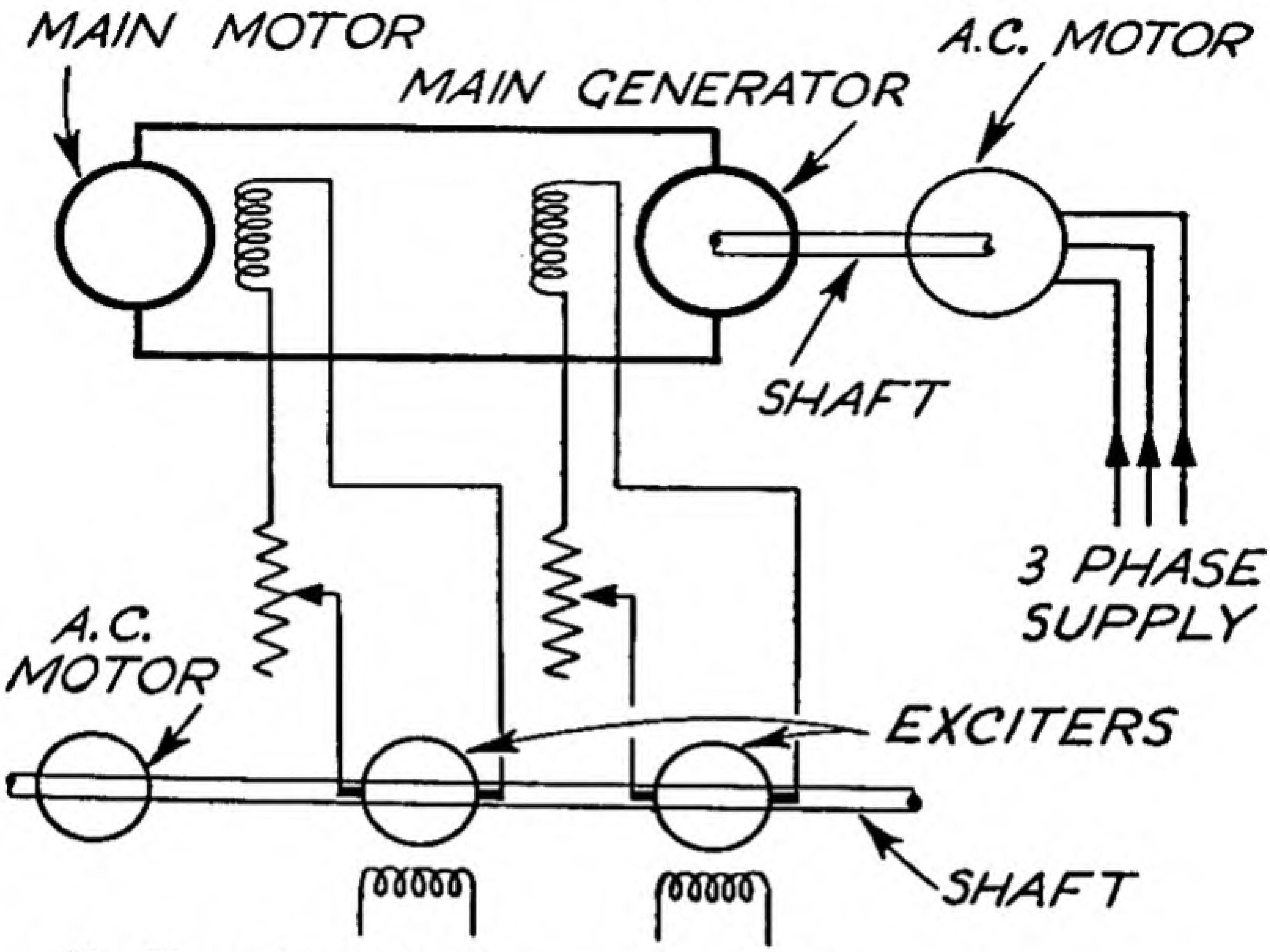


Fig. X, 3.—Ward-Leonard speed control for very large motors

flywheel on the generator shaft might cause a heavy surge on the mains. The flywheel gives up some of its energy to the motor-generator set, which in turn is able to supply momentarily a heavy current without overloading the mains.

Electronic Control

Electronic motor speed regulators employ rectifiers of the grid-controlled type which convert the a.c. supply into d.c., and make possible exact control of the speed, torque, current requirements, braking and reversal of the motor. The expense of such equipment is fully justified in cases where remote control of some intricate process, demanding exact speed regulation, is necessary. The rectifiers provide control of both the armature and field circuits.

Starting of Motors

Starters for workshop d.c. motors are provided with a series of studs, traversed by a moving arm, and connected to resistance elements which are cut out in turn as the arm moves from the "rest" position

to full speed (Fig. X, 4). These resistances are connected in the armature circuit, but the starter is so arranged that immediately the handle moves to the first stop, full field is provided, to give the maximum torque at starting. When the handle has been moved to the "full speed" position, a small electromagnet, in series with the field winding, holds it there (the "hold-on coil") against the pull of a return spring. This provides protection against voltage failure, as if the field fails the

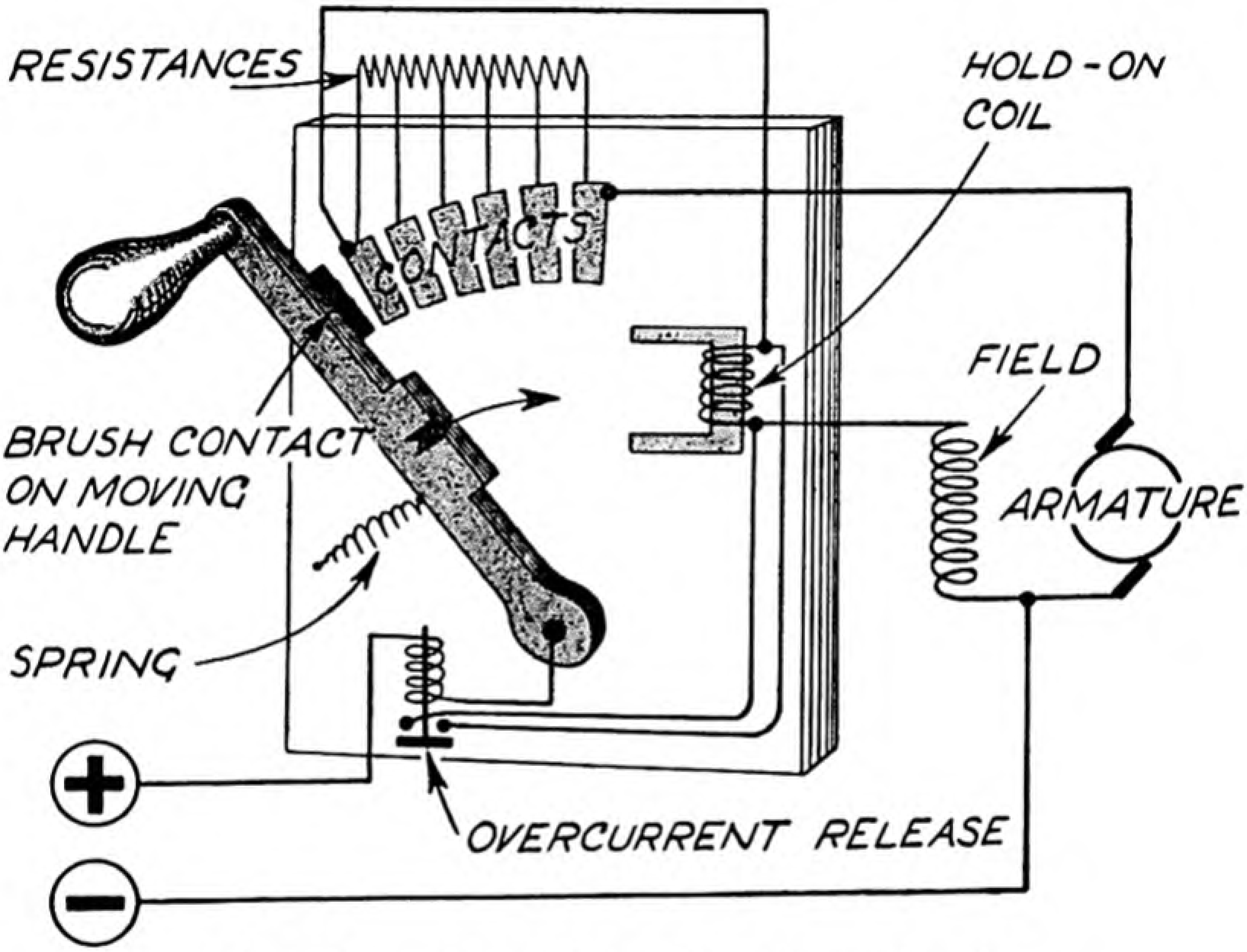


Fig. X, 4.—Starter for a direct current motor

motor might run away, or if the mains failed, the motor might otherwise be switched on again without armature resistance in circuit, and damage might result. There is usually an over-current release, which consists of a small electromagnet in series with the armature current, which attracts a lever, carrying contacts. If the armature current is too great, the over-current release will exert sufficient pull, against a spring, to close the contacts; these contacts short circuit the terminals of the hold-on coil, thus allowing the return spring to pull the handle back to the "off" position.

In the case of series-type d.c. motors, starting is effected by inserting resistance in the series circuit and removing it again notch by notch as the motor gains speed.

Most small modern three-phase a.c. motors are started by being switched straight on to the mains, as such motors do not take an excessive current at starting. For larger motors the star-delta system of starting is often employed (Fig. X, 5). The motor connections are brought out so that all six ends of the three windings are available and they are first connected to the mains "in star", and then when the motor has gained speed the starter switches are moved so that the windings are connected "in delta". In this way the current rush is lessened, as the voltage supplied to each winding is less in the star connection than in delta.

Motor starters are usually provided with fuses and since a squirrel-

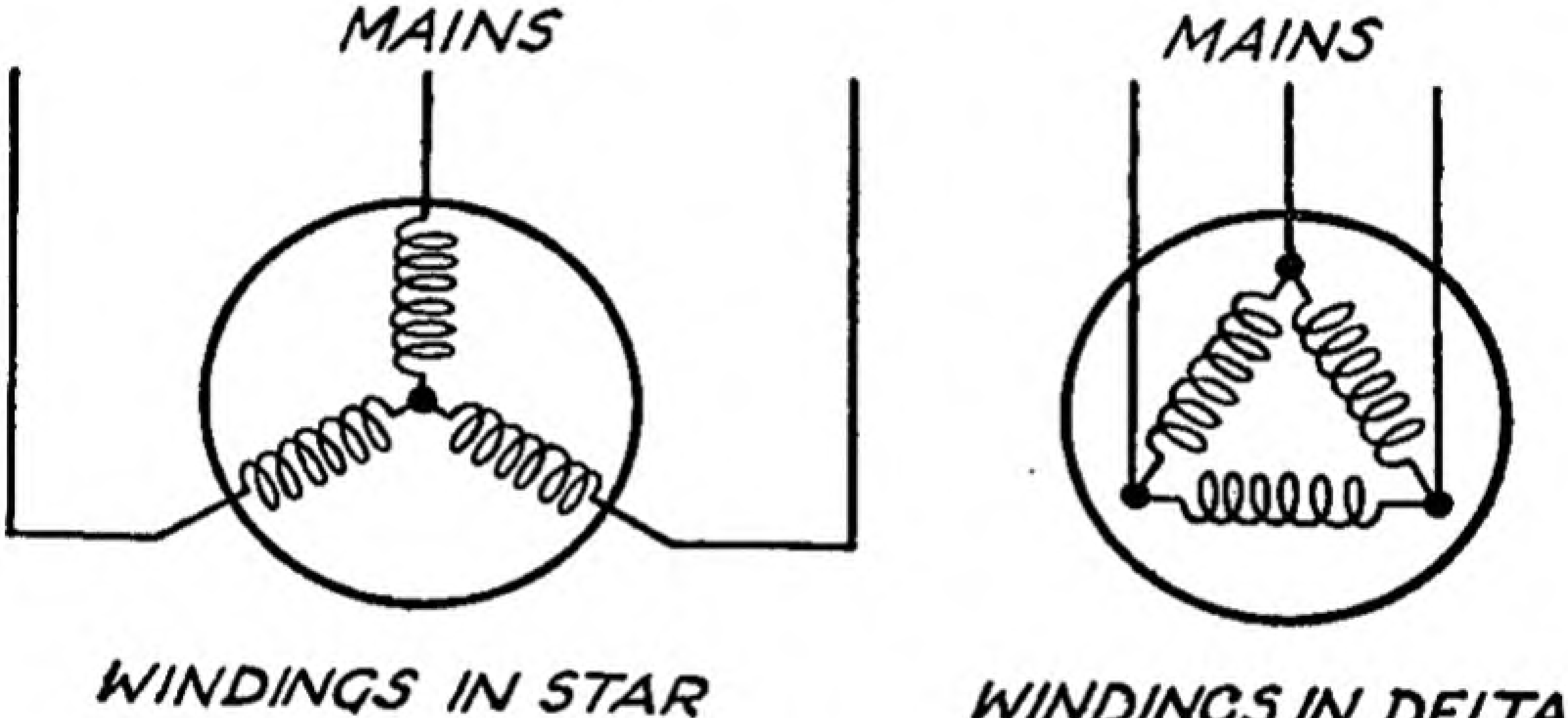


Fig. X, 5.—Motor connections as used in the star-delta starter

cage motor will take from five to seven times full load current at starting these fuses must be suitably chosen to withstand this degree of overload. Many motors are equipped with a type of protection which uses the bi-metal strip principle, and thus takes account of the temperature rise in the motor windings.

Single-phase motors are provided, as mentioned on page 61, with an auxiliary winding for starting purposes, and the starters for such motors usually take the form of a switch which has to be held over manually against a spring until the motor has run up to speed, when the handle is released to fall back to the "run" position. This handle carries contacts that first put the auxiliary winding in circuit and then cut it out when the motor has established its own rotating field.

Remote control of all types of motor may be achieved by means of contactors, so that a small, low voltage circuit carrying only the current necessary to energize the contactor coil can be extended as

far as necessary, and can be made to start up motors of all sizes automatically or manually, as required.

Protection of Motors

All types of motor are made up in various forms of enclosure. It is important to ascertain that the motor chosen will be suitable for its purpose in this respect. The simplest type of enclosure is the open type, in which there is no special protection against the entry into the motor of dust and water. Such motors must only be installed in situations where they are protected against these enemies, and moreover their bearings are not usually designed, from the oil-retaining point of view, for use at any other angle than with the motor shaft horizontal. The makers will supply special types of motor for use with the shaft vertical.

If a motor is to be protected, means must be found whereby the internal heat, due to the iron and copper losses, can be evacuated. Some types of enclosure employ a partially enclosed frame, with an internal fan on each end of the shaft which draws air in through louvres which prevent the largest dust particles from entering and also protect against water unless this is thrown directly at the louvres.

Totally enclosed motors may be of two types. In one, the carcass is provided with large external cooling fins, and the windings are so arranged that they are in close contact with the carcass, so that the heat is transmitted rapidly to the exterior. An external fan then blows air over the fins, to dissipate the heat. The other type of totally enclosed motor uses a cooling system of pipes, which are built in to the frame. Air or sometimes water circulates in these pipes and removes the heat.

The motors used in a small workshop for drills and lathes are usually of the three-phase, open type, and speed control, if any, is carried out mechanically by such means as gearing or three-speed belt pulleys. Motors of this type require very little maintenance, and as long as the lubrication is attended to as advised by the makers, the only necessary precautions to be taken are to ensure that oil, water or dust cannot gain access to the motor windings. At the same time, in protecting the motor, care must be taken not to shield it in such a way that the heat generated cannot get away.

Electric Welding

Welding equipment may be a.c. or d.c. In the latter case a motor-generator set is employed to convert the mains current to d.c.

The welding arc is struck between the work piece itself and an electrode, which consists of a thin rod of special iron coated with a special flux. This is held in a suitable holder with an insulated handle and a shield to prevent sparks from injuring the hand. The welder must always wear suitable glass goggles to avoid damage to the eyes from the intense brightness of the arc.

The arc voltage is of the order of 70 or 80 volts, and therefore the transformer used for a.c. welding must step down the voltage to this figure and must of course be of the two-winding type (i.e. not an auto-transformer) since the connection made to the workpiece is in effect equivalent to earthing the side of supply, and this could not be done if an auto-transformer were employed.

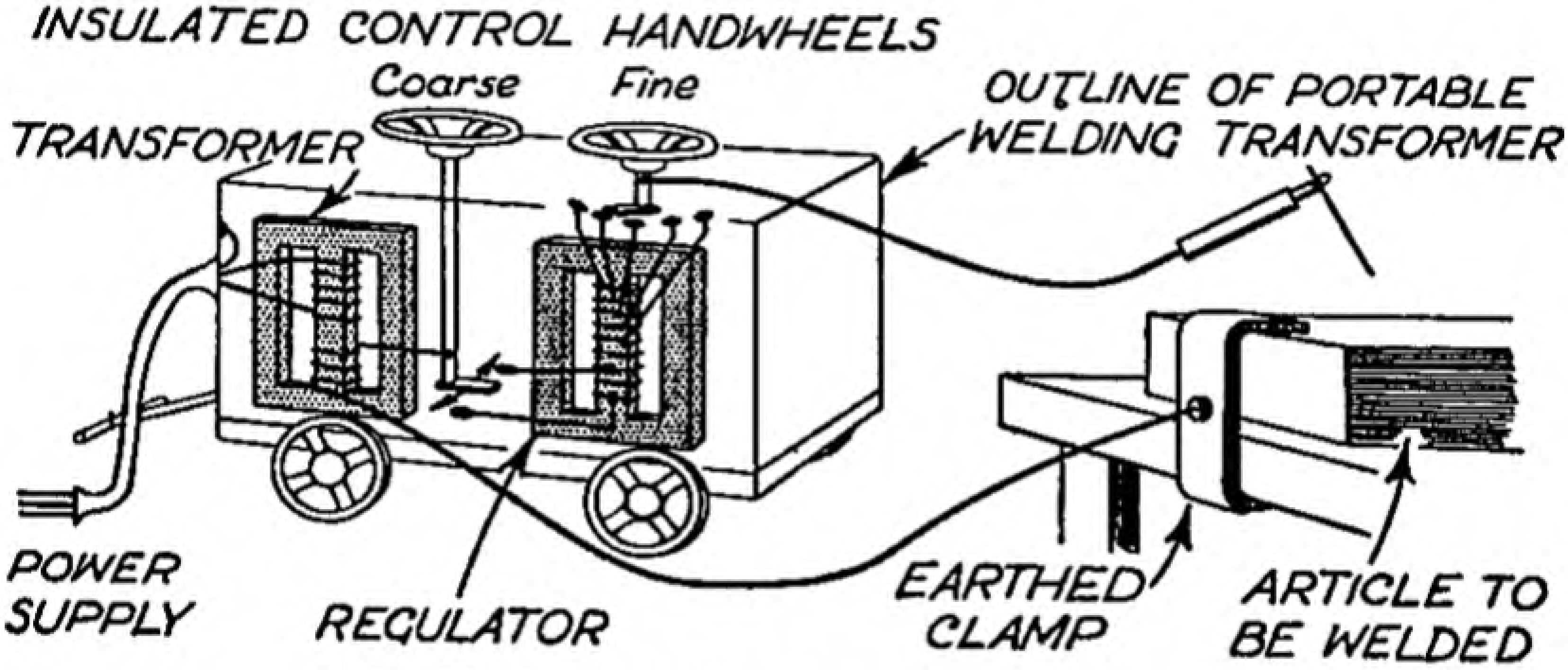


Fig. X, 6.—Welding transformer circuit

The arc presents a variable voltage drop, and if the windings of an ordinary two-winding transformer were connected directly across it a number of troubles would rapidly arise since the arc current during short circuit, when the electrode happened to stick, would be excessive and would probably blow the main fuses on the primary side of the transformer or would operate the appropriate circuit breaker. There is thus the need for a choke coil to limit the current to a predetermined value and this is known as the regulator. It comprises a transformer-type frame of laminations, on which there is a single winding, while the frame usually includes an air gap to provide the proper inductance characteristics. The welding circuit needs a higher voltage when starting and a regulated voltage when running. The regulator usually has a tapping switch, so that the current may be adjusted, and this may have coarse and fine control positions (Fig. X, 6).

In some cases the regulator takes the form of a choke with a movable

iron core, which can be screwed in or out to adjust the amount of impedance it offers to the welding circuit. The choke also fulfils the function of displacing the current in the welding circuit well behind the voltage as a "bad" power factor is, in the case of welding circuits, an advantage. If the current and the voltage passed through their zero points at the same moment, there would be a danger that the arc would tend to go out at every zero point. When they are displaced by perhaps 70 or 80 electrical degrees, the maximum current, which generates the maximum heating effect, occurs at one instant and the zero point occurs at a later instant in each cycle, so that the heat inertia in the weld tends to keep up the ionized condition of the ambient air due to the hot metal, and so facilitates the restriking of the arc.

The usual welding equipment employed in small workshops consists of a square or circular tank containing the oil-filled transformer, which can be moved to the site of the work. Great care must be taken when connecting up to ensure that the tank is properly earthed and that the earth return circuit on the low voltage side is properly made by means of large section cables or copper bars. Otherwise, there will be danger of fire through arcing at some inefficient joint, and there will also be a high resistance in the welding circuit which will militate against successful welding. The ordinary single-phase one-operator welding set draws a considerable single-phase current peak from the mains, and this may give rise to unbalance trouble on the three-phase system. The supply authority should be consulted before connecting up any but the smallest welding set. There is also the question of power factor correction on the mains side, since the normal welding load is of low power factor and may cause difficulties. Power factor correction capacitors can be employed to improve this condition.

In larger workshops the problems of single-phase unbalance are dealt with by the use of three operator sets, using a three-phase transformer so that a more even sharing of load between the phases can be achieved.

Direct current welding has many advantages, although the equipment is considerably more expensive. The usual d.c. welding unit consists of a motor-generator, the d.c. machine having special characteristics to suit the welding load. The generator is usually of the compound type with shunt and series fields and may also include a special pair of brushes, which are normally short circuited and which serve to control the armature reaction so as to provide the correct welding characteristics. The machine must give the right voltage whatever the load, and the additional brushes prevent overload if there is a short

circuit. In large workshops, where the nature of the process is such that d.c. must be used, rectifier units may be employed, but this would not be usual unless there were a very considerable number of operators continuously at work.

Apart from the straightforward welding methods whereby an operator applied the weld to the seam or other part where it is needed, there are a number of special welding machines which are increasingly used even in the smallest workshop.

Special Welding Processes

A number of welding processes operate on the resistance principle. Here an open arc is not drawn by the application of an electrode, but instead the heat generated by the passage of current through the metal itself is raised until it is sufficient for welding purposes.

The spot welding process consists of holding two thin sheets of metal together under strong mechanical pressure, and then discharging through the point of contact a "pulse" of current, which has the effect of heating the metal surfaces at this point, and so welding them together. The pressure is held on for a moment after the actual passage of current, and thus forges the weld together. The machines used for this purpose employ two large circular electrodes, one of which is fixed in a vertical position, while the other can be brought vertically downwards to rest on it under the influence of spring, hydraulic or pneumatic pressure. The body of the machine contains the welding transformer, and a timing device is interlocked with the pedal which is pressed down to clamp the two pieces to be welded between the electrodes (Fig. X, 7). In most such machines the welding timer ensures that the correct sequence of operations is carried out, i.e. the pressure is applied, the welding current is passed for a predetermined period, the pressure is held on, for a further set time and the pressure is released, opening the jaws of the welding head.

Spot welding machines may be used for building up large sheet metal assemblies and are made up, with the necessary pneumatic or other equipments for exerting pressure, in various forms. These include a bench machine for small welds and a portable machine suspended from a crane with the welding tongs depending from it, thus being capable of being applied to awkward parts of an assembly, and there are many other special forms for special purposes. In many cases the electrodes are water cooled to prevent them from being burnt away and the water supply is carried to them by means of flexible pipes. The water exhaust should always pass through a funnel so that its

flow can be observed. Special machines are made for welding a number of spots at once or for welding a series of almost continuous spots along a seam, this being known as stitch welding, the spot welds overlapping each other.

A variant of the spot welding process is seam welding, where rollers are used on the ends of the electrodes and the pressure is continuously applied, the electrical impulses being applied in the form of pulses, usually produced by the use of electronic timers attached to the welding transformers. As the work slowly passes between the

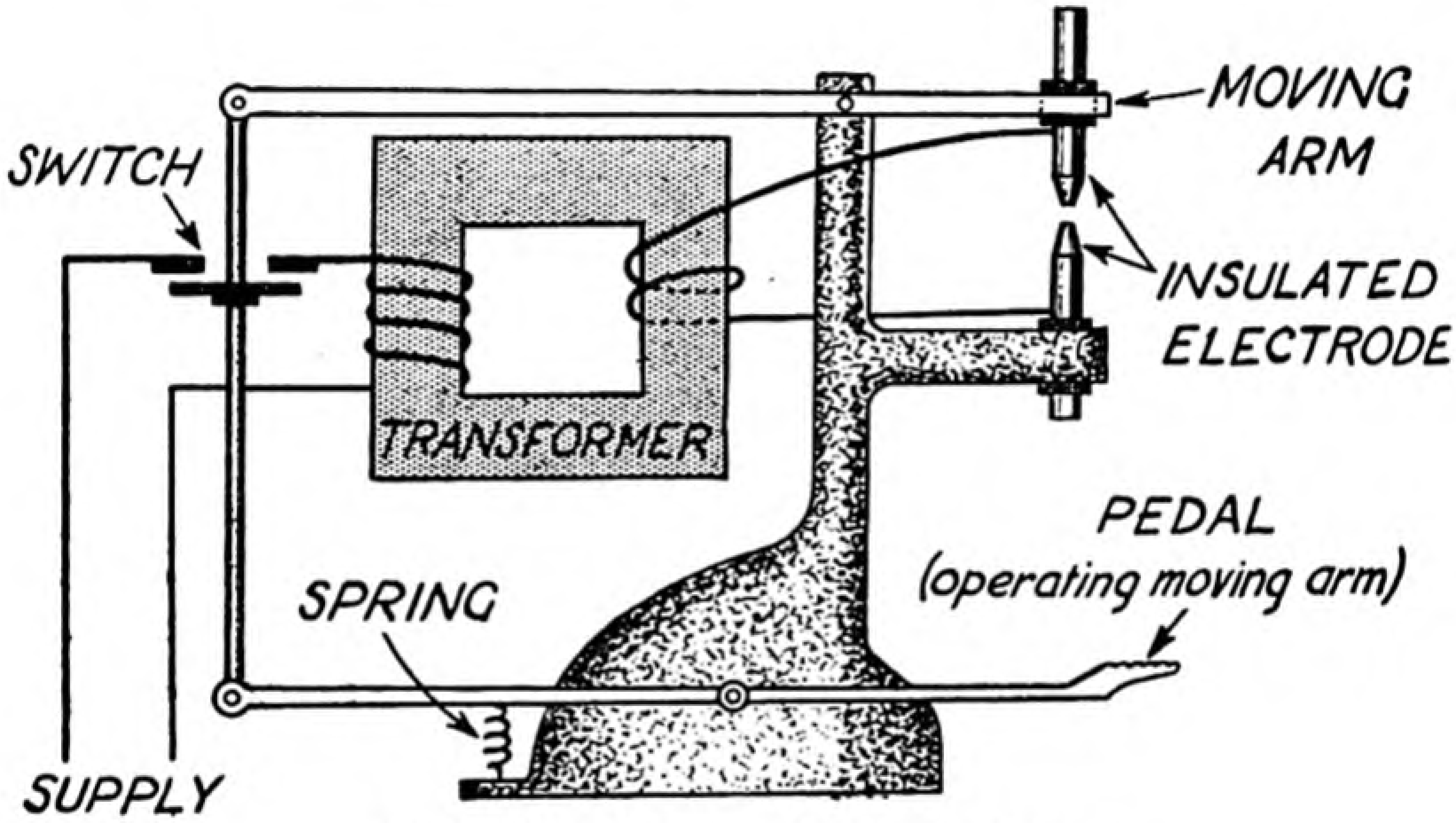


Fig. X, 7.—Spot welding machine

rollers, the series of welds caused by the pulses of current overlap one into the other and a continuous welding seam is thus produced.

Projection welding is another variation of the resistance welding method. Where sheet metal assemblies are to be joined together they are stamped out in such a way that ribs are produced at the points where joints are to be made. By placing a piece in which there is a rib on to the corresponding flat surface of the other piece, a point contact is made between them, where welding heat may be generated by suitable application of current. A machine in which pneumatic or hydraulic pressure is available is used to clamp the two pieces together, and the current is then applied between them for a predetermined time, thus melting the ribs and causing them to form a firm welded joint between the two portions.

Butt welding is a method used for joining rods, bars and wires by clamping the two ends horizontally in a machine in which screw

or hydraulic pressure can be brought to bear, so that the ends to be welded can be pressed together with great force. Voltage is applied to the two clamps, which are suitably insulated, and the machine then causes them to approach. An arc is set up when they are at first lightly in contact, and the timing arrangements on the machine are such as to retain this arcing condition for sufficiently long to raise the temperature of the ends high enough for them to weld. The clamps then press the ends firmly together, resulting in a weld which is as strong as the wire itself. In a variant of this process, known as butt flash welding, the same type of machine is used but the parts are brought into contact before the current is applied, and the high resistance of the rough surfaces where they meet is sufficient to set up a welding temperature, and the pressure then forges the weld.

Another welding device used in mass production workshops is the stud welder for applying screwed studs to metal surfaces, for example, to fix the studs which hold on a manhole cover. The stud is held in a special chuck and is applied to the work piece to which a connection has been made for the return circuit. The chuck-holder contains a powerful spring and also includes a mechanical device which first lowers the stud to within arcing distance of the metal, and then—once the arc has created a pool of molten metal—plunges the stud downwards into it with great force so that the weld is properly forged. This operation may be made entirely automatic in sequence, and studs may be applied at the rate of two or three a minute.

For the various types of resistance welding machines mentioned above, a range of electronic control equipment has been developed, based mainly on the principles of the thyratron. This is a gas-filled electronic valve, which has the special property of "triggering". A grid is provided between anode and cathode, and the valve is non-conducting until the negative grid voltage is reduced. The valve will then conduct until the a.c. voltage reaches its next zero point, when the current flow will cease unless the grid once more allows it to flow. By using this device, very light currents which can be set up by electronic valve circuits can be used to trigger off very large currents for exact periods which may be very small—less than 1/100th of a second—by using large thyratrons or as they are known in the larger sizes ignitrons. Many large welding machines use this type of control.

High-frequency Heating

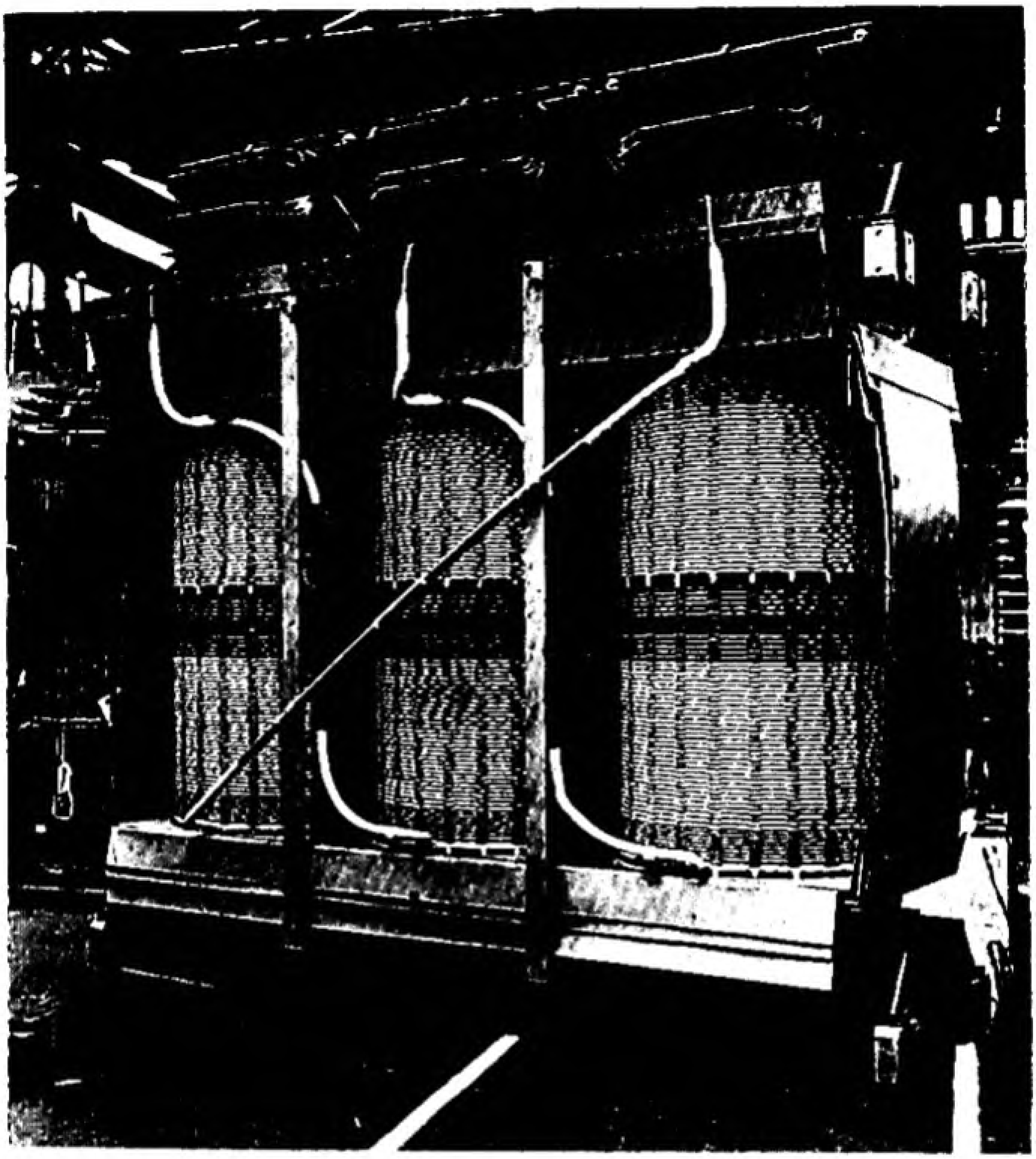
A type of equipment widely used even in the smallest workshop for heating purposes is the high-frequency heater. This may

take two forms, known as induction heating (for metal objects) and dielectric heating (for non-metal objects).

The induction heating machine depends for its operation basically on the ordinary transformer effect. If the frequency of a particular circuit in which a transformer is connected is increased, the linkage between the primary and secondary coils will also be increased. If the secondary coil is a short-circuited ring, current will flow in it; and to obtain a very high current with a reasonable size of transformer, it is necessary to bring up the frequency to a figure much higher than that used for normal commercial purposes. The induction heater therefore consists of some form of high-frequency generator. The principle is used for heating large quantities of metal being melted for foundry purposes, and the metal itself then forms, in effect, a short-circuited turn, since a coil carrying the high frequency is placed near it so that the magnetic flux cuts the metal in the crucible. For these very large applications of induction heating, a motor-driven alternator, which may give out current at 5,000 c/s, is used.

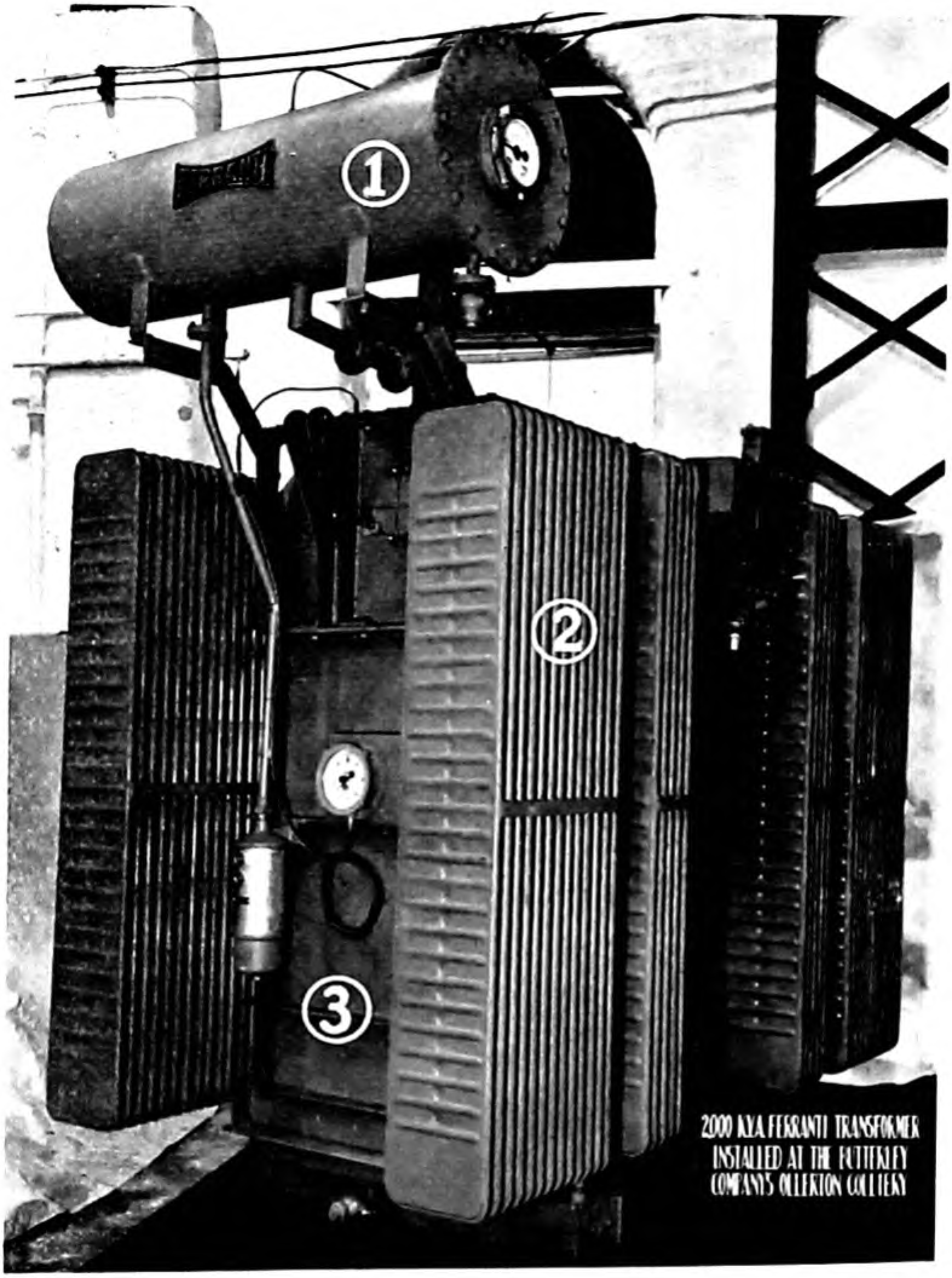
For smaller applications the high-frequency alternator is expensive and moreover has a definite frequency limit at about 5,000 c/s, whereas much higher frequencies are needed for efficient induction heating on a smaller scale. The induction heater used in workshops employs electronic valves as oscillators to produce frequencies of the order of a million cycles per second, and the output from these valves is applied to a special "work coil" which usually takes the form of a coil of copper tube through which water circulates, so that the tube itself does not become destroyed through overheating. This work coil is arranged to surround the piece to be heated, which may, for example, be a bolt which has to be case-hardened. The high frequency flowing through the work coil generates corresponding high-frequency currents in the metal, and as these are operating in short circuit, the eddy current losses in the metal generate heat.

Among the advantages of the induction heating method is the fact that the heat is generated right inside the work piece. When a bolt, for example, is heated in the ordinary way by means of a flame or an oven, the heat passes from the outside to the inside, and therefore at any given moment in the early stages of heating the heat is unequal, since the outside is hotter than the inside. Moreover, the thermal efficiency of induction heating is much greater, since any external flame-heating method must result in a great deal of lost heat. In the induction method heat is set up only in the work piece, and nowhere else. No flame-heating method can give the exact control heating necessary for perfect tempering or special heat treatment, while with



English Electric

PLATE 9. The core and windings of a three-phase power transformer, outside its tank



Ferranti

PLATE 10. A typical power transformer for indoor use. The oil conservator (1) allows for expansion of the oil when heated by the effect of the load. The oil contained in the tank (3) is cooled by the radiators (2)

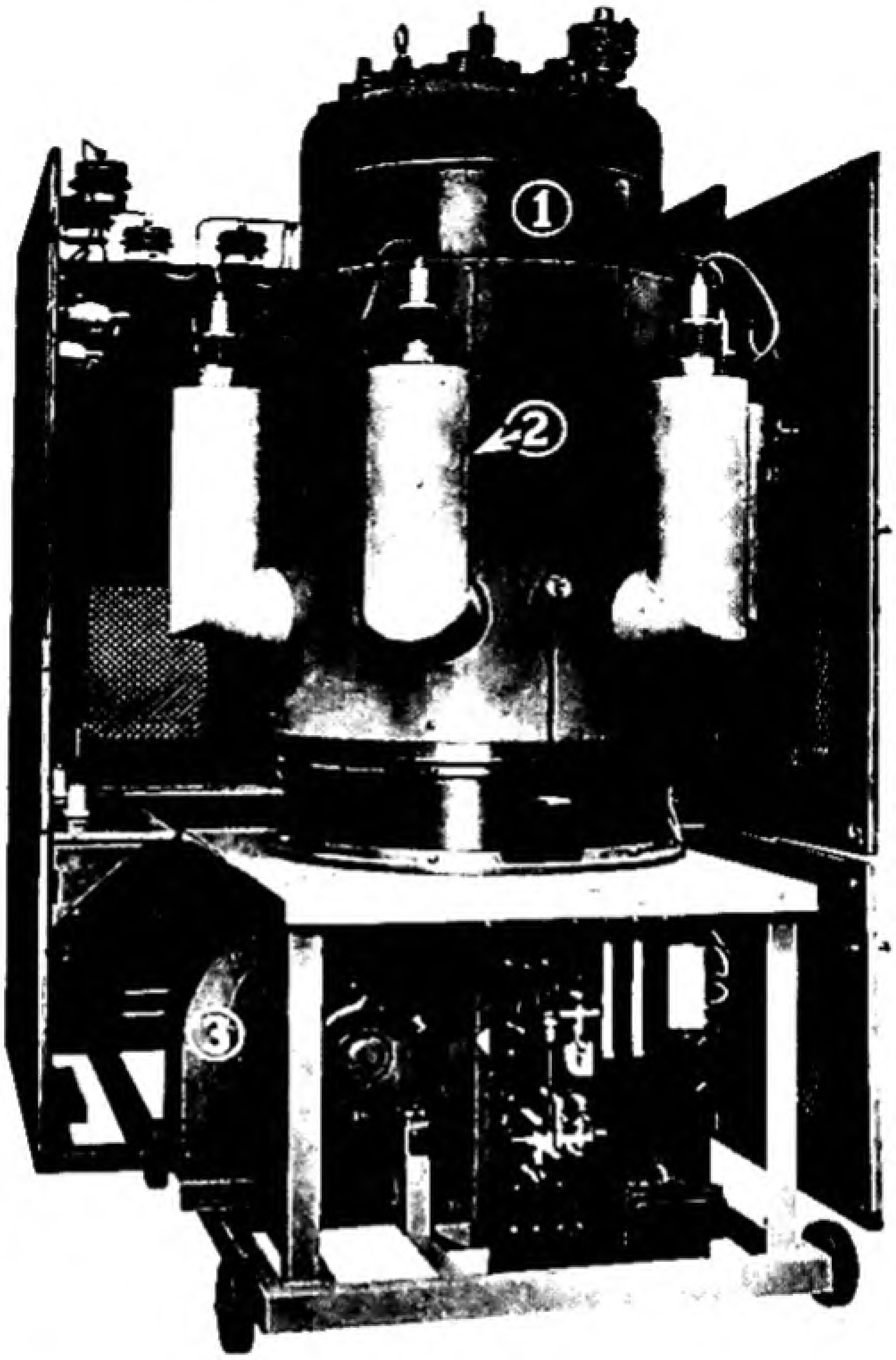


PLATE 11. A mercury arc rectifier of the steel tank type, for traction or industrial service. (1) The steel tank; (2) the anode arms; (3) the cooling fan

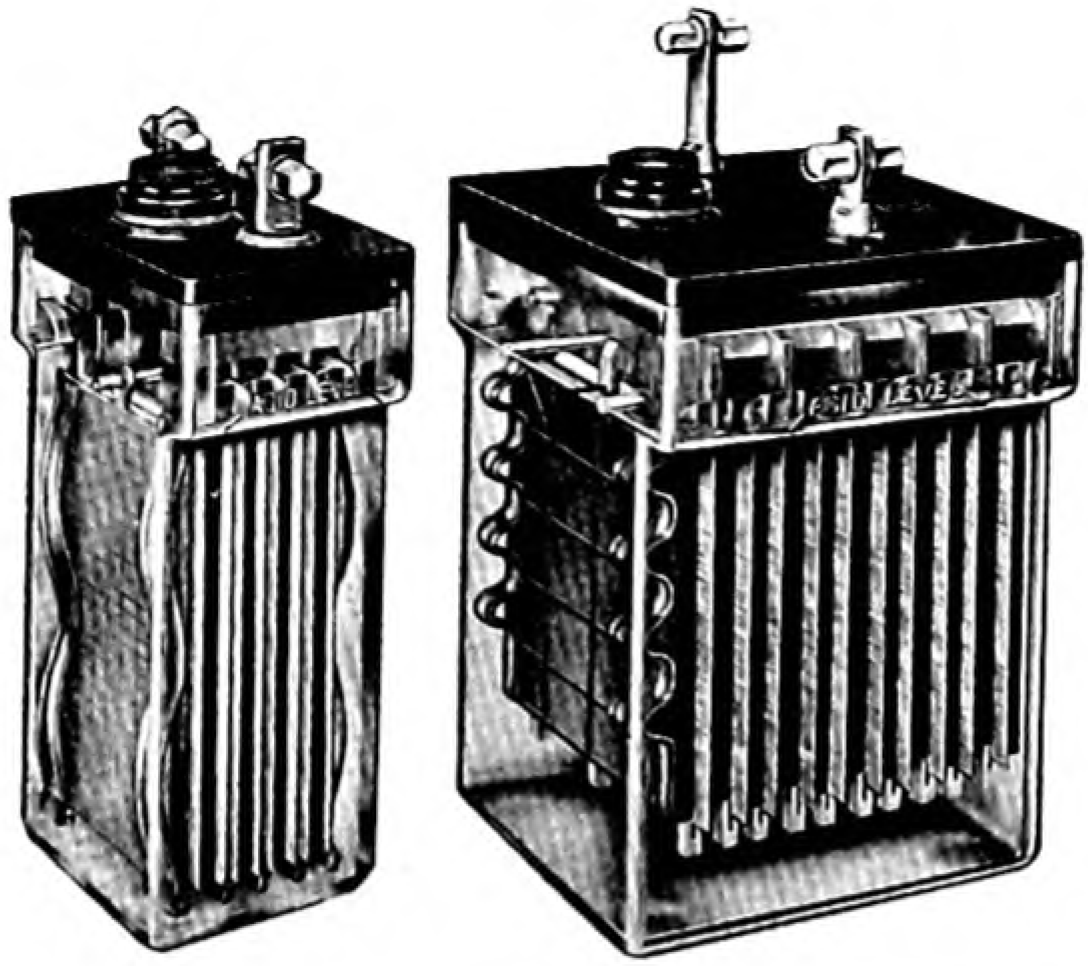
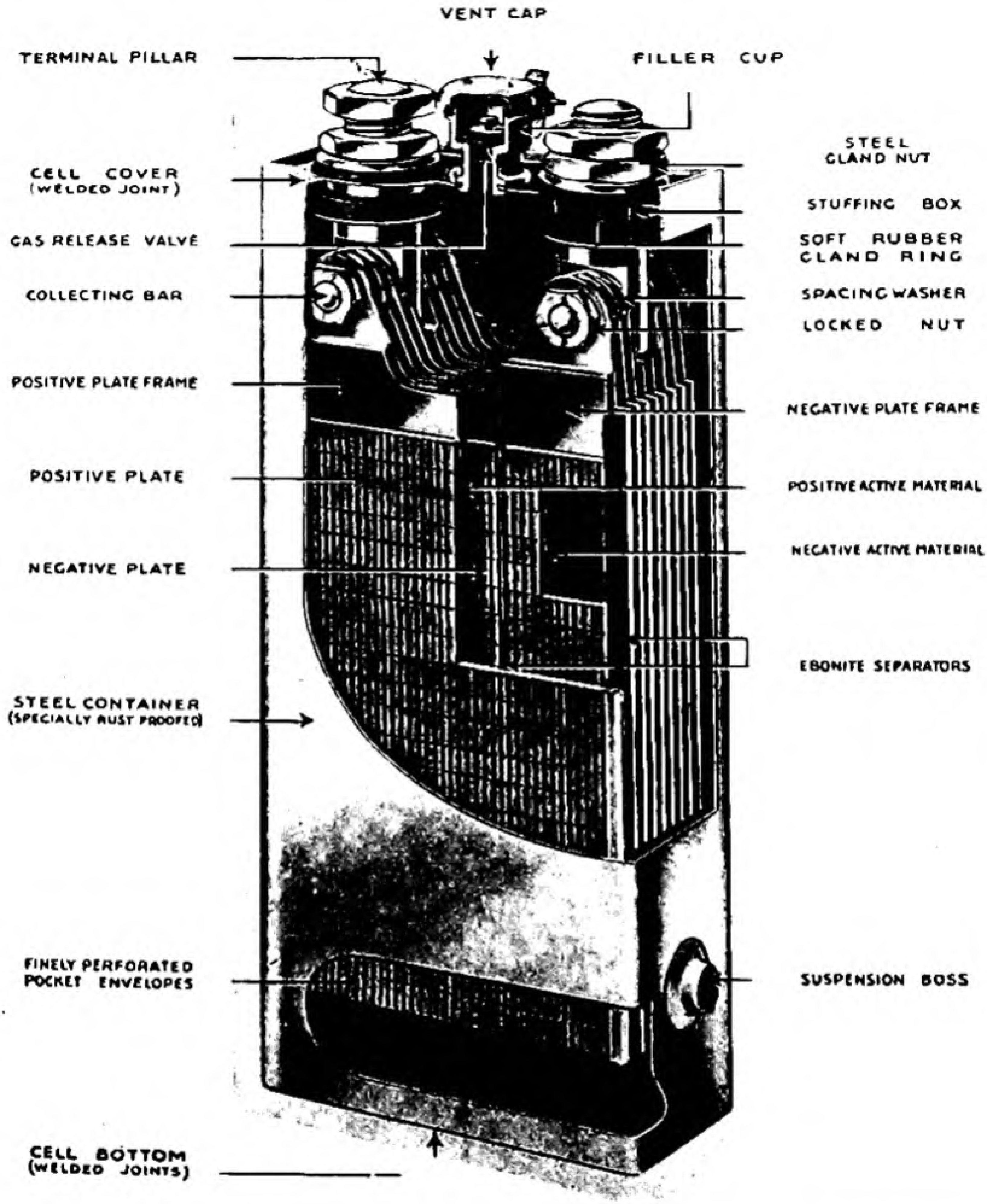
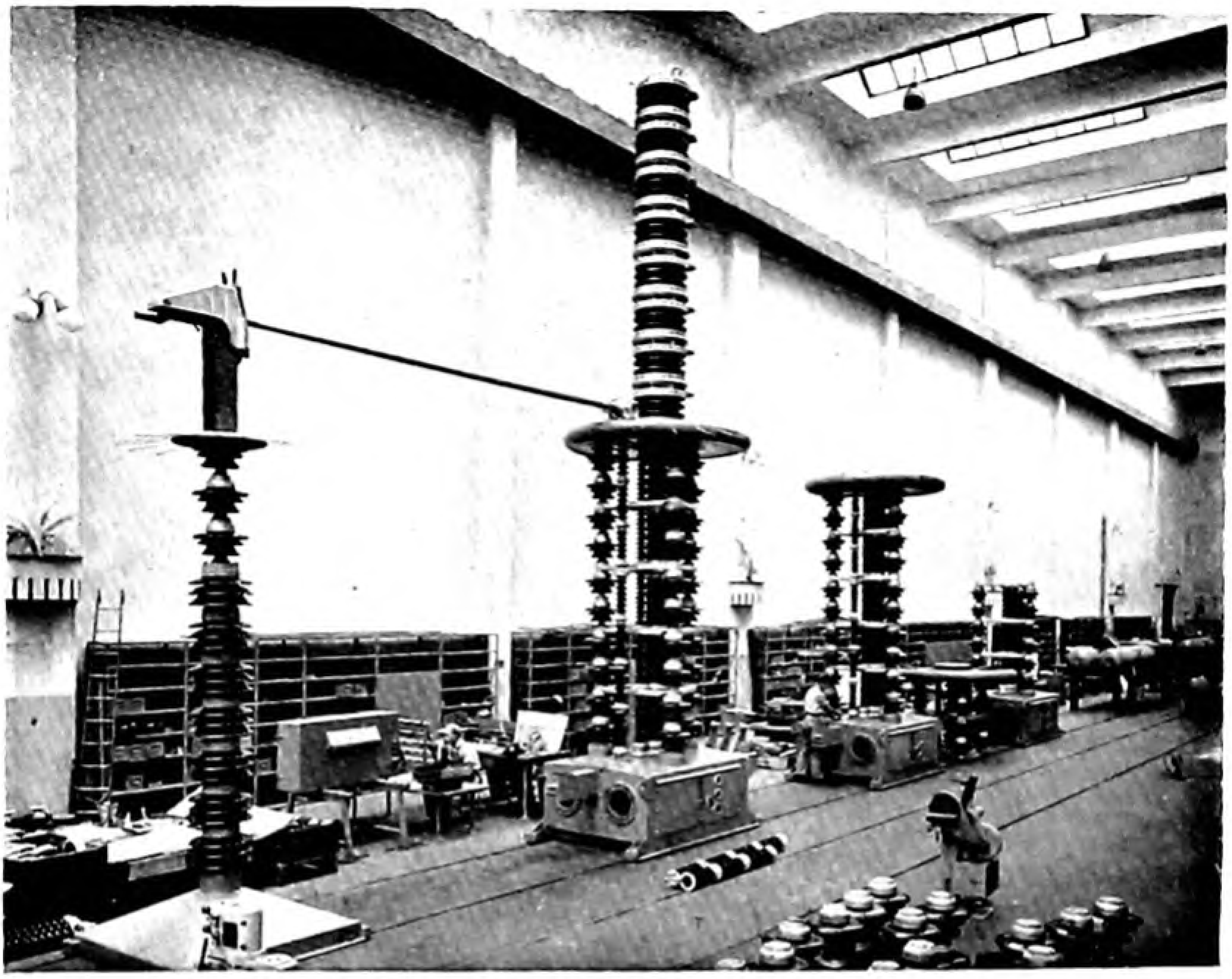


PLATE 12. Lead acid storage batteries (accumulators). The alternate positive and negative plates are held apart by separators usually made of wood or porous rubber



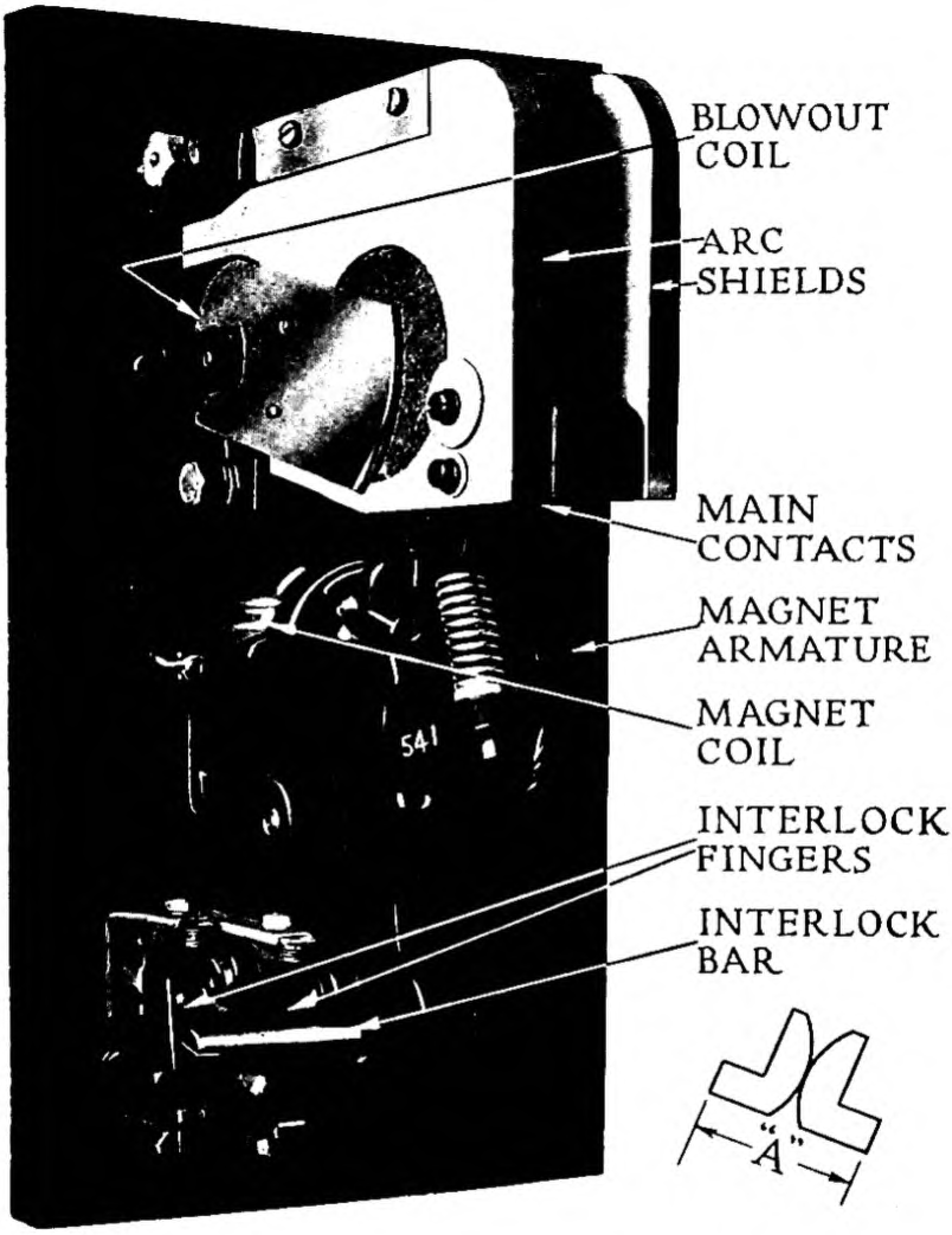
Alkaline Batteries Ltd.

PLATE 13. An alkaline storage battery. The separators are usually made of hard rubber (e.g. ebonite)



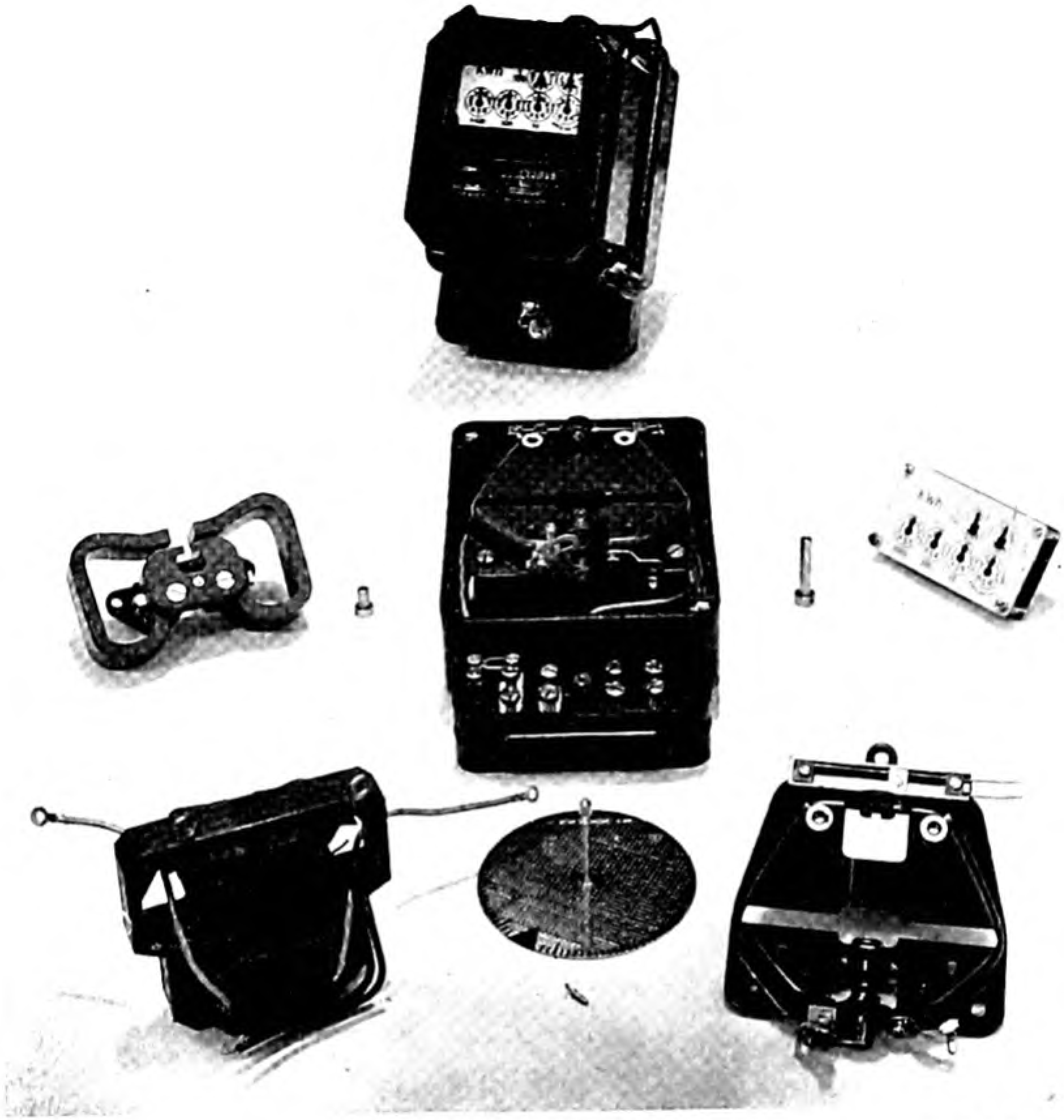
A.S.E.A.

PLATE 14. One of the three single-phase units making up a 380,000 volt air-blast circuit breaker. The actual circuit-breaking elements are situated in the top part of the high column of insulators in the centre of the picture, taken in the workshop while the circuit breaker was under construction



Igranic Electric Co. Ltd.

PLATE 15. A typical contactor



English Electric

PLATE 16. The component parts of a house service meter (kWh meter) seen complete at the top. The brake magnet is seen at the top left, and the rotating disc at the bottom of the picture, centre

the induction method this can be achieved within 1° or 2°F. Further advantages are that the heating or melting process can be carried out in a vacuum, or in some special atmosphere such as nitrogen gas which is required for heat treatment purposes. Finally, there is no contamination of the metal by impurities in the flame, and the production of eddy currents in the metal causes a natural motor action resulting in stirring taking place, so that the melt will be homogeneous throughout.

Induction heating is used for surface hardening to a very wide extent, since it is possible to arrange for the heat to be generated on the surface only, if required. The effect of changing frequency enables the depth of penetration to be controlled and the higher the frequency the greater the "skin" effect. This is due to the fact that the reactance of the paths taken by the current inside such a work piece as a cylindrical object vary with the frequency; and at very high frequencies indeed the whole of the current is in effect driven outwards to the surface. Induction heaters are made up in cabinet form and are usually completely automatic in operation; they may have powers as great as 25 kW.

Dielectric heating is used for such purposes as glueing and welding suitable types of plastic material. The basic principle is that of the capacitor (Fig. X, 8). If a capacitor is included in an a.c. circuit the flow of power through the circuit has, in effect, also to flow through the dielectric. This is not a strictly scientific explanation, but will serve to illustrate the functioning of the dielectric heater. Whenever power flows through a material loss occurs and this loss takes the form of heat.

Referring back to Chapter I, in which the passage of electrons along a material was discussed, the application of alternating electrical stresses at each side of the dielectric between the capacitor plates might be said to raise the energy level of the atoms and release electrons which in turn create heat by friction within the material. This effect is the basis of dielectric heating, and since the higher the frequency applied to an a.c. circuit in which there is a capacitor, the greater the current, it follows that very high frequencies are used when it is a question of heating up materials which are normally considered as non-conductors. Frequencies of the order of 10 million to 200 million c/s per second are used for dielectric heating, using special types of valve oscillators. The output is brought to the plates of a capacitor between which the material is situated, and when the power is switched on for a given period, the material may be melted or heated to an exact degree.

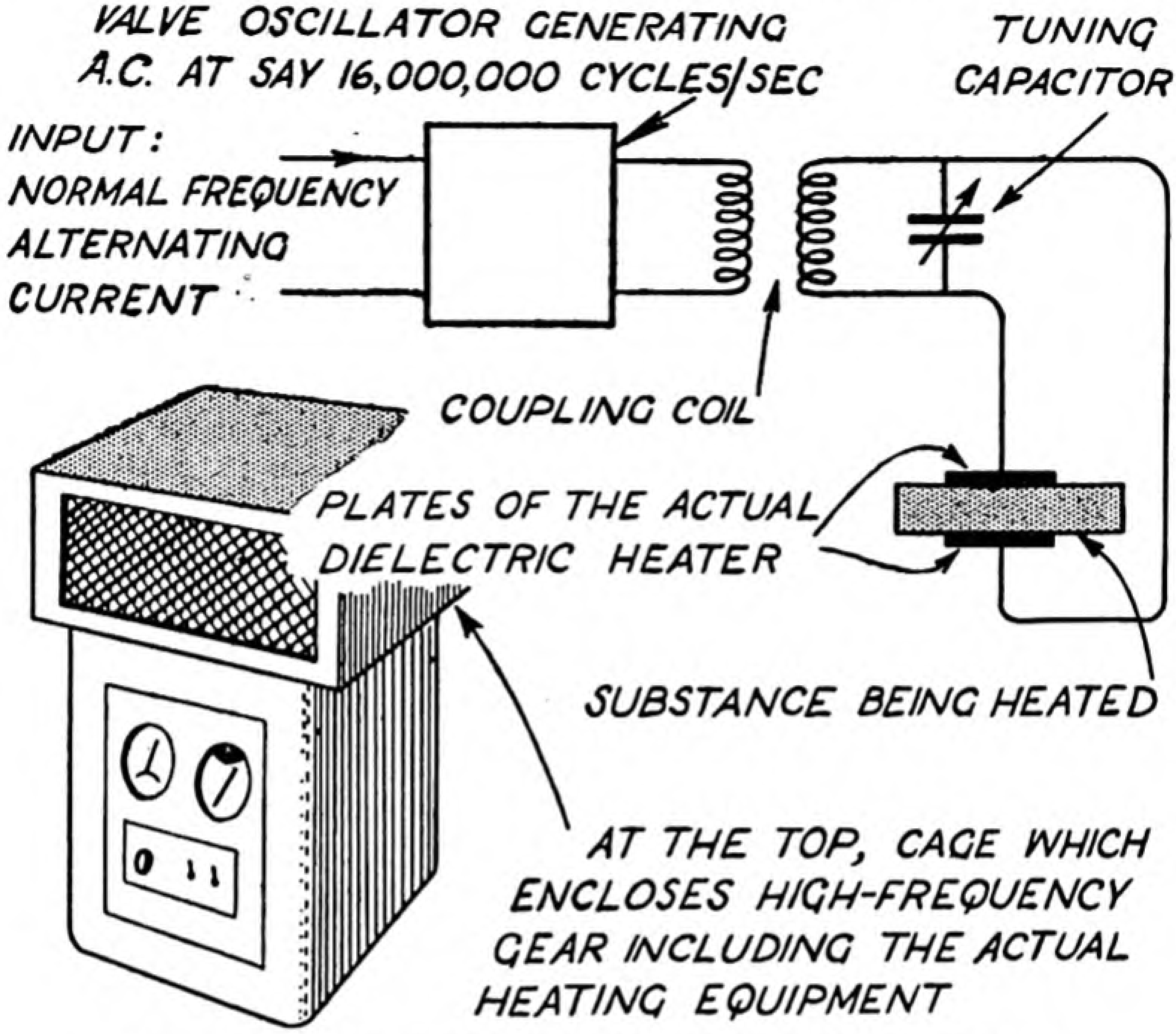


Fig. X, 8.—The basic principle of the dielectric heater

A great many moulded plastic materials are made from moulding powders which have been melted by means of dielectric heating; and a number of laminated wooden assemblies are made up with special synthetic plastic glues susceptible to being heated by dielectric heating methods, and which will then set instantly. Suitable plastic sheets may be welded together as if they were metal by the same spot welding and seam welding methods as are used for metal sheets.

Dielectric heating is applied in a wide variety of ways and among them are the dehydration of such materials as foodstuffs and textiles. If, for example, a piece of cloth made of cotton is placed between the poles of a dielectric heater the heating effect can be so carefully controlled that it boils off the absorbed water before the heat reaches such a degree as to damage the fabric. Dried vegetables, such as peas, may also be produced in this way, with the advantages that the heat is generated perfectly cleanly and within the body of each individual pea so that all moisture is removed, and there is no unwanted cooking effect caused by the high degree of external heat necessary to penetrate inside the body of the pea.

Other applications of dielectric heating include the extermination of pests in grain. Very often large quantities of grain are destroyed by the presence of weevils, and suitable dielectric heating applied to the grain, as it passes over a belt, will result in the body fluids of the insects being raised to such a temperature that they are killed, without in any way affecting the grain.

Dielectric heating is also used for cooking, and by its aid experimental loaves of bread have been created entirely without crusts, since the crust arises from the higher degree of heating on the outside caused by normal methods. Dielectric heating creates the heat uniformly throughout the loaf. It is also used for medical purposes, since suitable electrodes enable controlled heat to be produced inside the body tissues.

Dielectric heaters are made up in cabinet form, and again are suitable for entirely automatic operation. Owing to the very high frequencies employed, the actual connections between the oscillating valves and the work have to be carried out with special co-axial tubes, as otherwise they themselves would form capacitors of such a capacitance that they would absorb most of the energy.

Electro-Plating

The electro-plating process is one in which metals are coated with a thin layer of another metal either for purposes of protection against corrosion or rusting, or for improvement of appearance. A number of layers, sometimes of different metals, may be applied one after the other.

A direct current at a potential of some 3 or 4 volts is passed from an anode to the metal to be coated acting as the cathode, through an electrolyte made up of a salt of the metal of which the coating is to be made. The anode may be a block of the pure coating metal or it may be a neutral substance from the electro-chemical point of view, such as carbon.

The amount of metal deposited from a chemical solution of a salt of that metal is proportional to the current, and when large amounts of metal are to be deposited by plating, the current may run into thousands of amperes. Power is usually provided by means of a motor-generator set, with an a.c. motor driving a d.c. generator in which the commutator is very long so that ample brush area is provided to deal with the large currents concerned. A number of generators may be connected in parallel to provide the requisite current. Both dry plate rectifiers and mercury arc rectifiers are used, the dry plate rectifier being employed for the smaller installations.

The most vital part of an electro-plating process is the preparation. All objects are liable to have an almost imperceptible coating of grease, and this must be removed by the use of special solvents; very often the material to be plated is also boiled in a caustic solution. If there is an oxide scale, such as rust, the material is pickled, this process consisting of dipping in a solution of an appropriate acid. Electrolytic cleaning processes may be used, involving the passing of a current from an anode to the work piece through a caustic solution.

The usual form of plating bath is a container (Fig. X, 9) lined with lead or ebonite and arranged so that it can be heated, since the electro-chemical processes usually proceed more rapidly when the

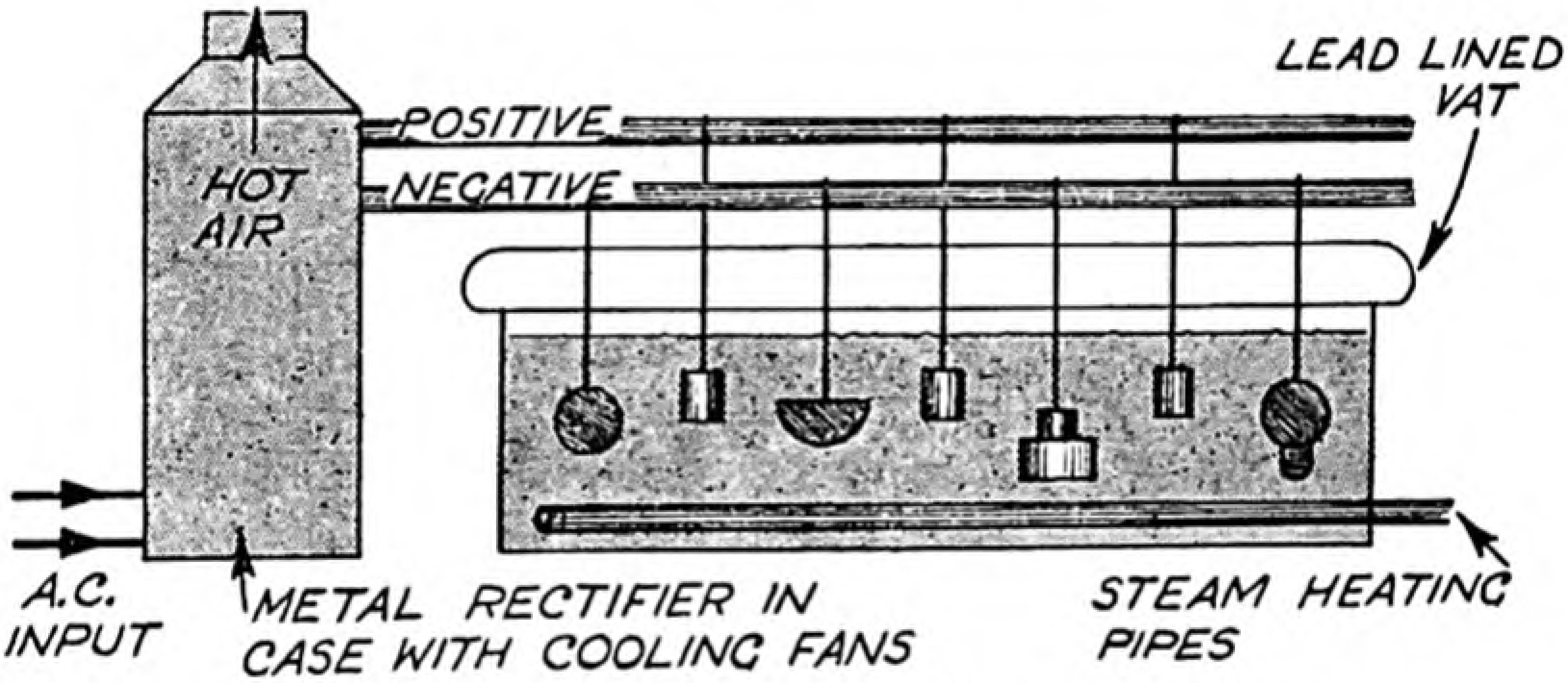


Fig. X, 9.—The elements of an electro-plating bath

solution is warm. The anode is inserted at one end of the bath and the work is suspended from suitable holders at the other, although sometimes several anodes and the work are arranged in alternate layers. Parts of the work which are not to be plated, for example screw threads, are covered with suitable rubber pieces to prevent the plating action.

For copper plating, which is often carried out for typographical purposes, an electrolyte of copper sulphate and an anode of copper is used and the current density is of the order of 20 amperes per square foot. For chromium plating, steel is usually first plated with nickel and then with chromium, the work being washed carefully between each plating process. Silver, gold, zinc, cadmium, tin, lead, palladium and rhodium are all metals that are applied by plating processes. In many cases poisonous salts, such as cyanides, are used, and great care must be taken when they are being handled.

For the protection and decoration of aluminium, the anodizing process is used, whereby a film of hydroxide which acts as a protective

layer is built up on an aluminium surface. In this case the aluminium is used as the anode, and the electrolyte is chromic acid, ammonium phosphate or sulphuric acid, while dyes may be added to give a coloured finish which is highly effective and pleasing.

By depositing a very thin layer of graphite (which is a conductor) on non-conducting materials such as wax moulds they may also be covered with metal by an electro-plating process. It is also possible to deposit rubber by what is known as electrophoresis. This phenomenon is due to the movement of a suspended particle or a colloid under the influence of a potential difference and the anode forms the substance on which the deposit is to take place. By adding vulcanizing materials, a hard rubber deposit can be produced.

One of the uses of electro-plating in the workshop is to build up worn metal parts by plating on to them a layer—usually of chromium—which is very hard, and which can then be machined to exact size.

The plating of large numbers of small objects is often carried out by automatic methods, one such being the use of a rotating barrel in which the objects are placed and which revolves in a vat containing the anode and the electrolyte. In this way they are continuously tumbled about and so uniformly plated all over.

If plating is carried out in a workshop, it should take place in a screened-off portion with proper ventilation, since the fumes that arise may be dangerous to health. The floor should have ample drainage, and facilities for washing of hands, etc., must be readily available.

The Electrical Test Bench

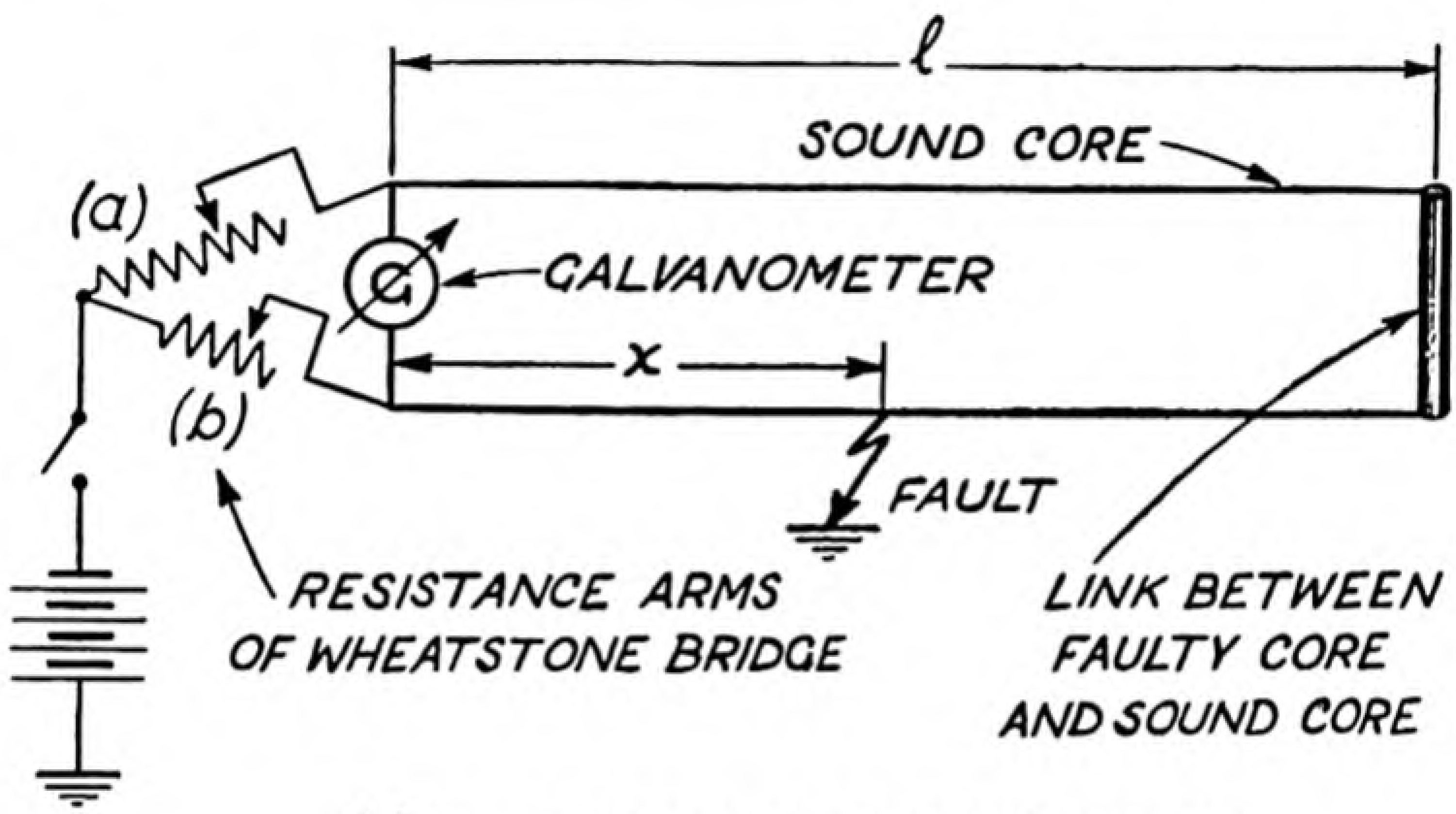
All workshops should contain an electrical test bench. This should be under the supervision of a qualified electrician, and should be inaccessible to unauthorized persons.

The first essential is a set of reliable instruments. These should include two or more voltmeters, which may usually be of the a.c. type, unless there is a considerable quantity of d.c. apparatus in use, and they should be scaled up to the highest voltage used anywhere in the factory. In many cases this will be 440 volts across the phase wires of the three-phase mains. The usual voltmeter scale which will take in this figure is 600-volts full scale. Two or more ammeters should be provided, and here current transformers will also be needed so that an ammeter with 5-amperes full scale can be used for any current up to some hundreds of amperes.

One of the most vital measurements to be taken on the factory test bench is that of insulation resistance, and here the Megger is

universally used. If a large number of tests are to be taken a motor-driven Megger will be found to be especially valuable.

If there are long cable runs in the factory, a fault locating set may be found to be valuable. This takes the form of a Wheatstone bridge and a galvanometer, the cable being so connected at the remote end from the test point that one sound core (of equal length to the faulty core) is connected to the core on which there is a fault. Two arms of



When galvanometer reads zero:

$$\frac{a}{b} = \frac{l+(l-x)}{x}$$

$$x = \frac{2bl}{(a+b)}$$

Fig. X, 10.—Method of locating an earth fault on a cable run

the Wheatstone "lozenge" then comprise the distance from the test point to the fault, and the distance from there to the remote end and back again to the test point, respectively (Fig. X, 10).

The other two arms are the ratio arms of the bridge itself and by suitable adjustment until a zero reading is obtained on the galvanometer when battery power is applied between the junction point of the ratio arms and earth, the distance of the fault can be ascertained as a percentage of the total length of the double run of cable.

For finding the resistance of coils, resistors and the like, the potentiometer is extremely useful. It consists of a variable resistance and a

standard cell, a special form of primary battery whose voltage has a very high degree of constancy. The Wheatstone bridge may also be used for this purpose. Text books on electrical instruments also give details of other bridge-type devices for measuring capacitance and inductance.

A phase rotation meter is a useful device which may be improvised quite easily, if necessary. The direction in which a motor will run when connected to the three phases of a supply system depends on the connection to the stator being made so that the phases arrive at the motor in a particular order. If a motor is to be taken from one location

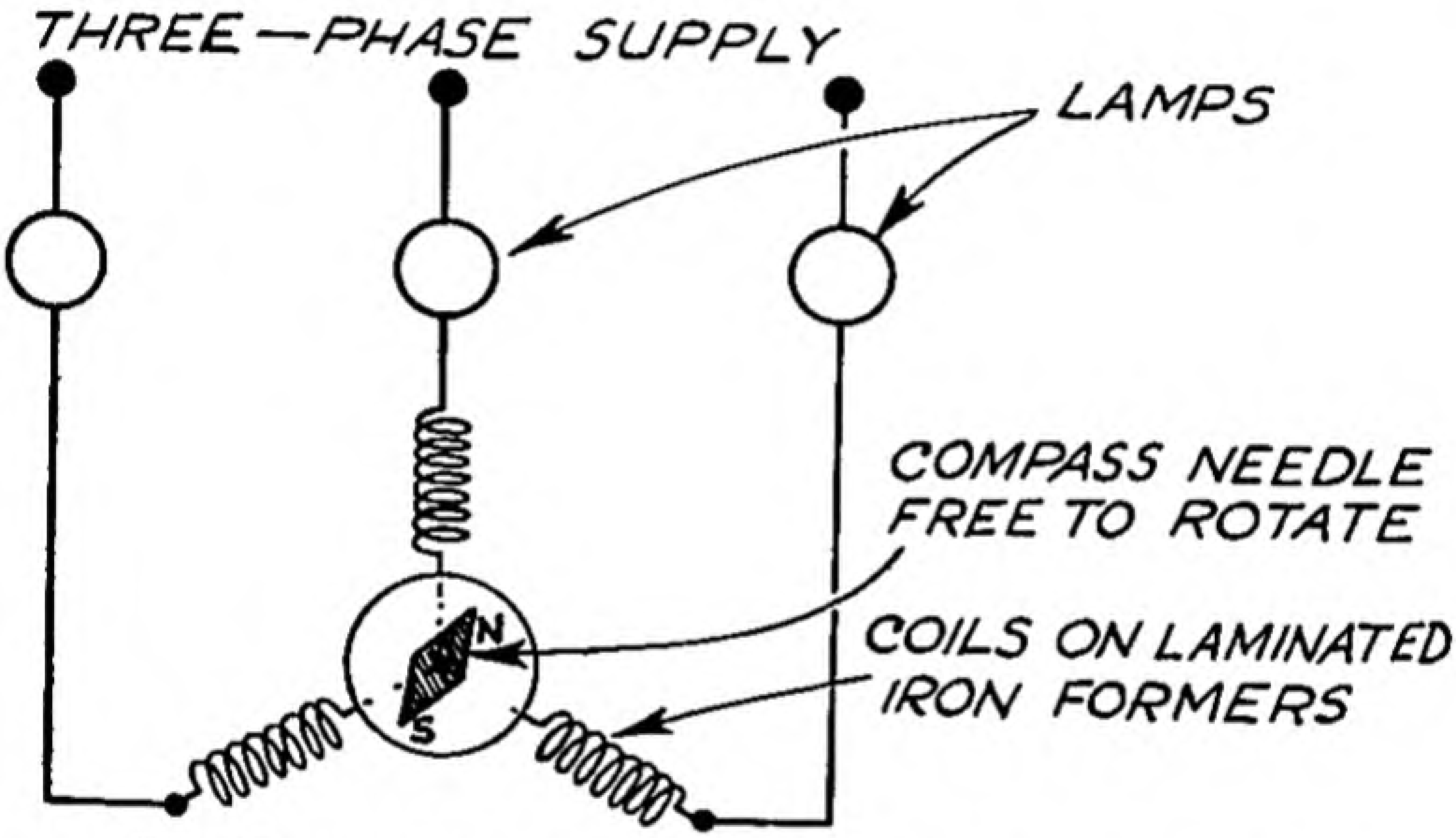


Fig. X, 11.—The principle of the phase rotation meter

to another and the phases are not marked red, white and blue, as they should be, to ensure that the motor will run the same way in the new location a phase rotation meter is used. Three lamps are connected in series with three small coils wound on laminated formers, the centre being joined together to form a star connection (Fig. X, 11). The coils are so disposed that an ordinary magnetized compass needle can rotate across them. If lamps are inserted in the lampholders to keep the current to a suitable small value, and the three outer ends of the coils are then connected to the three-phase wires, the compass needle will commence to rotate in one particular direction, say, clockwise. If the phase rotation meter is now applied to another set of three-phase wires of unknown phase rotation it will revolve either clockwise or anti-clockwise, depending on whether the second set of

wires has or has not the same phase rotation as the first. By checking the numbered terminals of the meter against the phase wires, it can be ensured that the motor will run in the same direction.

For the testing of d.c. armatures a special device may be made up whereby an electromagnet of a suitable shape takes the place of the field winding and induces in the armature windings voltages which may be measured by means of a special probe, having two prongs which will rest on two adjacent commutator bars. The voltage may be read off on a suitable voltmeter and as the armature is rotating in the testing jig equal voltages should be obtained all the way round. Unequal voltage reading will indicate a faulty coil.

Most electricians will devise for themselves testing jigs of one sort or another for their own special purposes. For example, checking the continuity of cartridge fuses may be carried out very rapidly by means of a jig on which the fuse can be placed, making contact between two bars connected in a bell and battery circuit. If a particular type of contactor often has to be tested, a device which includes an ammeter to measure the current in the coil and spring-loaded clips which measure the pressure on the contacts against some form of spring balance may easily be made up to suit conditions.

Precautions

When carrying out routine maintenance work the utmost care should always be taken to ensure the safety of all personnel engaged and precautions to be employed under this heading usually consist of the withdrawal of fuses from the appropriate circuit, so that inadvertent switching on will not make it alive, and then locking up the fuse board and labelling the main switch "Danger, Men at Work". In large factories a permit system may be employed in which a man has to sign a card stating exactly which part is safe to work on, this card being countersigned by anyone who could possibly have access or authority for the switching on of the circuit.

Electricity in Farming

Electrical energy is used in agriculture and horticulture in many ways. There are electrically driven tractors, which pick up supply from a cable secured to a framework of poles which includes a counterweight arrangement to take up the slack. The farmer also uses electricity for grain drying, by having specially designed heaters over which warm air is driven by a fan powered by an electric motor. Electric

motors drive chaff cutters, animal food mixers and crushers. Electric motors are also used to drive harvesters, threshers, elevators, pumps and so on.

From the electrical point of view, these appliances do not call for special comment; the motors used must be robust and must withstand the ingress of dust and moisture to a considerable extent. Some manufacturers supply a sort of "universal" motor, equipped with pulleys of various sizes, and mounted on a barrow-like frame, which enables it to be wheeled to where it is needed, and plugged into convenient fixed power sockets.

In the dairy, electricity is used to provide the hot water and steam necessary for sterilizing and for this purpose the electrode boiler is often used. Electrical energy is also employed to drive the refrigerator motors for the milk coolers, and also the motors on the vacuum pumps for the milking machines. The heat pump has been developed for dairy use, so that the heat taken from the milk as it comes from the cow may be "pumped", at a higher temperature, to the sterilizing plant.

In horticulture, the use of soil heating is now widespread. Bare wires are buried in the seed beds, and are fed with low voltage (about 4 to 8 volts) from a transformer. The transformer may be of, say, 1 kW, and will feed several sets of wires, which are buried perhaps 6 in. to 8 in. in the soil. The wires are usually laid out in zig-zag fashion, with about 9 in. between adjacent wires. For large nurseries transformers of up to 25 kW may be used, and time switches and thermostats are used to switch the heating on and off automatically, in accordance with the ambient temperature and the time of year. Very greatly increased crop yields may be obtained in this way.

The amateur gardener who wishes to try experiments in the direction of electrical heating should make certain that the main-voltage side of the transformer is properly safeguarded against accidental contacts, and that the transformer frame is earthed (Fig. X, 12).

Soil warming is also carried out in glasshouses, and here another application of electrical energy is in sterilizing of seed bed soils. This may be done by steam, but a method which has many advantages is to use electrodes inserted in the soil, and then to pass current between them, thus heating the soil directly. High-frequency methods are also being developed for this purpose.

Artificial illumination of the greenhouse, to assist in propagation, is frequently used. Here care must be taken to ensure that the sprays used as insecticides do not contain corrosives injurious to the wiring. Mineral insulated cable, with watertight fittings, is recommended for

this work but lead-covered cable, with proper glands and again with watertight fittings, may also be used.

The space heating of a greenhouse may be carried out electrically by means of tubular heaters, which have the great advantage that they may be controlled thermostatically, and require no attendance.

In an experimental greenhouse produced in 1953 by the Electrical Research Association, the sunlight was controlled by the use of a continuous stream of green-coloured water pouring down over the roof, the thickness of the shading water layer being set by means of a photoelectric cell which controlled the pump which lifted the water

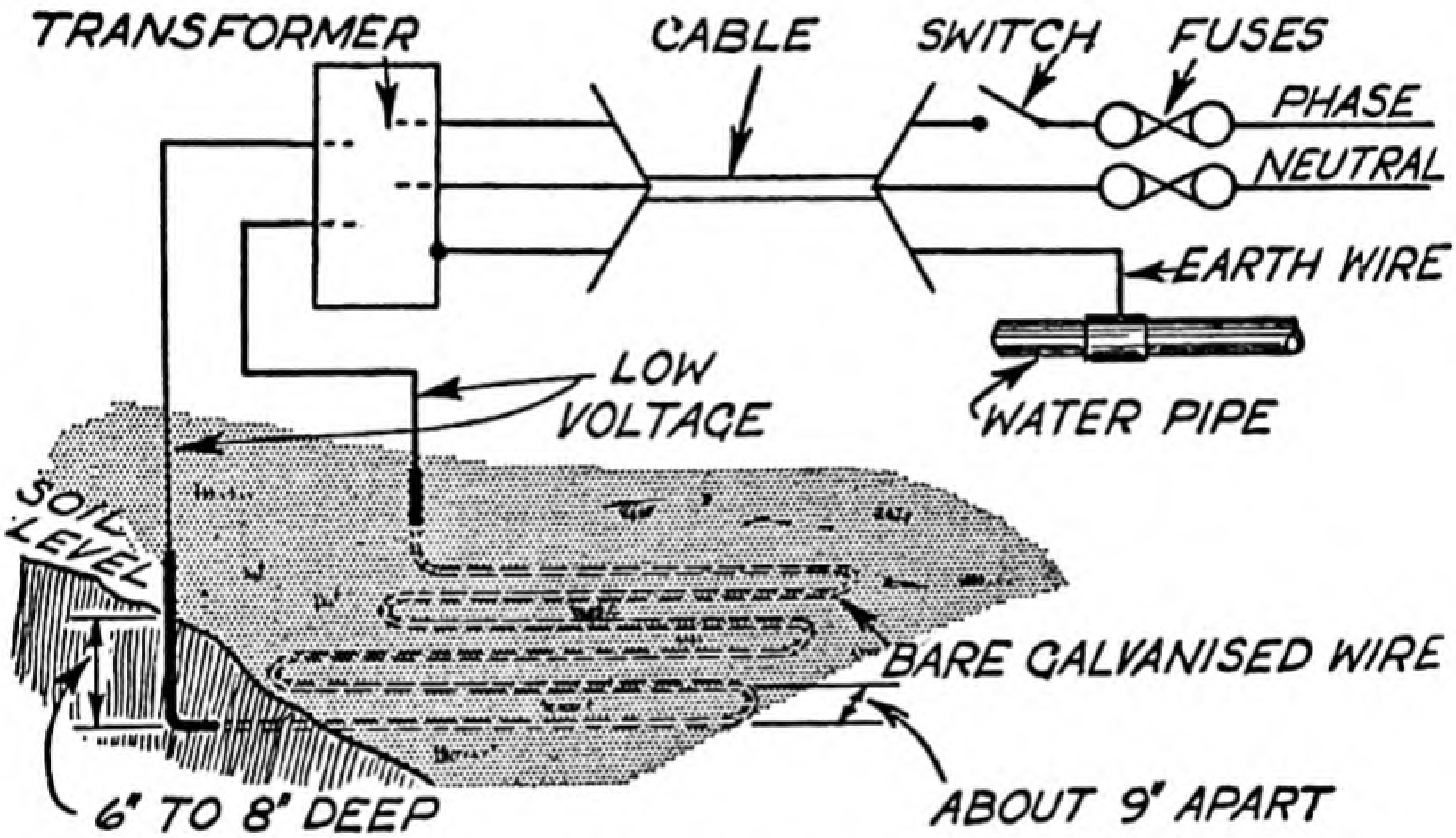


Fig. X, 12.—Soil heating by means of buried wires

up to roof level. The soil beds had water pipes and nutrient-supply pipes embedded below the surface, as well as soil-heating wires. All these were controlled automatically, so that exactly the right amounts of moisture and fertilizer could be applied continuously, at exactly the right temperature. The atmosphere in the greenhouse was air-conditioned, so that no insect pests could survive, and moreover the carbon-dioxide content could be controlled.

While it was not suggested, at the time of this demonstration, that commercial or amateur greenhouses would need to be equipped with all of these devices, nevertheless one or more of these aids to the horticulturalist are at present in use in many glasshouses. By the aid of the electrical engineer, it is possible to grow crops which are under perfect control, and which do not suffer from frost or insect pests, and

where the shape, size, flavour and appearance of each individual plant is exactly that required. Crops can, moreover, be grown at any season.

In the poultry house the use of extended daylight has long been used. Time switches are employed to switch on electric lights in winter, so that the birds have what amounts to a 14-hour "working day". Egg production may be materially increased. In recent years there have been experiments into what is known as "flash illumination", the principle of which is not yet fully understood. If powerful electric bulbs are turned on for only a few seconds, once or twice a day—in the early, pre-daylight hours—the improvement in egg production is almost as great as if the full "extended daylight" treatment had been given; the saving in current is considerable.

Electricity is also used for egg-candling lamps, and for heating boilers for making poultry mash.

The suburban gardener may use an electrically driven lawn-mower. The motor, of $\frac{1}{4}$ h.p. or perhaps $\frac{1}{2}$ h.p., may drive only the cutters, leaving the gardener himself to push the mower, or it may drive the roller as well. The problem in this type of device is to provide proper speed regulation; on the whole, the machines where the motor drives the cutters only is more satisfactory, since the operator can slow down the mower if the rate of cutting is too great for the power of the motor.

Electrically operated hedge trimmers use a small motor driving, through reduction gearing, an oscillating device, which causes two sets of teeth to work one against the other, and so cut through the twigs. A necessary safety precaution, to prevent fingers from being amputated, is an arrangement whereby one hand must be retained on a press-type switch while the other holds and guides the cutter.

Portable electric fences are now widely employed to confine animals to parts of fields when this is required. A series of short, insulated standards carries a wire connected to a battery giving a potential of from 6 to 12 volts. An animal nosing or licking such a wire experiences an unpleasant but harmless sensation at the point of contact and soon learns to shun the wire. The use of mains supply with a suitable transformer, instead of a battery, has not hitherto been recommended, but a safe and satisfactory system employing the mains for electric fences has now been devised.

CHAPTER XI

ELECTRICITY IN TRANSPORTATION

IN DEALING with electricity and its application to all forms of mechanical transport, we may first discuss electrical equipment on vehicles in which electrical energy is *not* used as the main motive power.

The problems faced by the electrical engineer called on to provide a supply of electrical energy on a moving vehicle may be divided under three headings. There is first the problem associated with a prime mover of varying speed; secondly there is the "scale effect" which renders the efficiency of small generators and motors much less than that of their larger counterparts; and finally the problem of storing energy at times when the prime mover on the vehicle is not in use.

These problems apply to cars, motor-cycles and even to bicycles, small boats and yachts. The supply of electrical energy on aircraft presents a somewhat different set of problems, as will be seen later.

CYCLE LIGHTING

The smallest type of electrical equipment on any vehicle is the lighting equipment on a bicycle. This may be provided in two ways. The head- and tail-lamps may be of the battery type, or a cycle dynamo may be fitted. The head- and tail-lamps normally used in battery lighting sets do not call for any particular comment. They employ dry batteries of two cells each, joined in series to give about 3½ volts, and the type of bulb employed is the "flash-lamp" type, although specially designed lamps with stronger filaments than those used for torches are available and give longer service.

Common causes of trouble with cycle lamps are mostly those arising from corrosion, which may have the effect of "rusting" the battery into the container so that it cannot be removed, or else it may damage

the simple type of switch used, in which a plunger at the top of the case is screwed down to make contact between the projecting brass strip on the top of the battery and the metal case itself which provides the return circuit, the other pole going directly to the single-point-contact on the bulb. A slight coating of vaseline on the inside of the battery case will assist in preventing corrosion, and the user should always seek to employ a type of lamp in which the maximum care has been taken to prevent the ingress of moisture.

The cycle dynamo consists of a small a.c. generator made up in a metal case with a milled wheel at one end and a single terminal at the other, the metal frame providing the return circuit. The dynamo

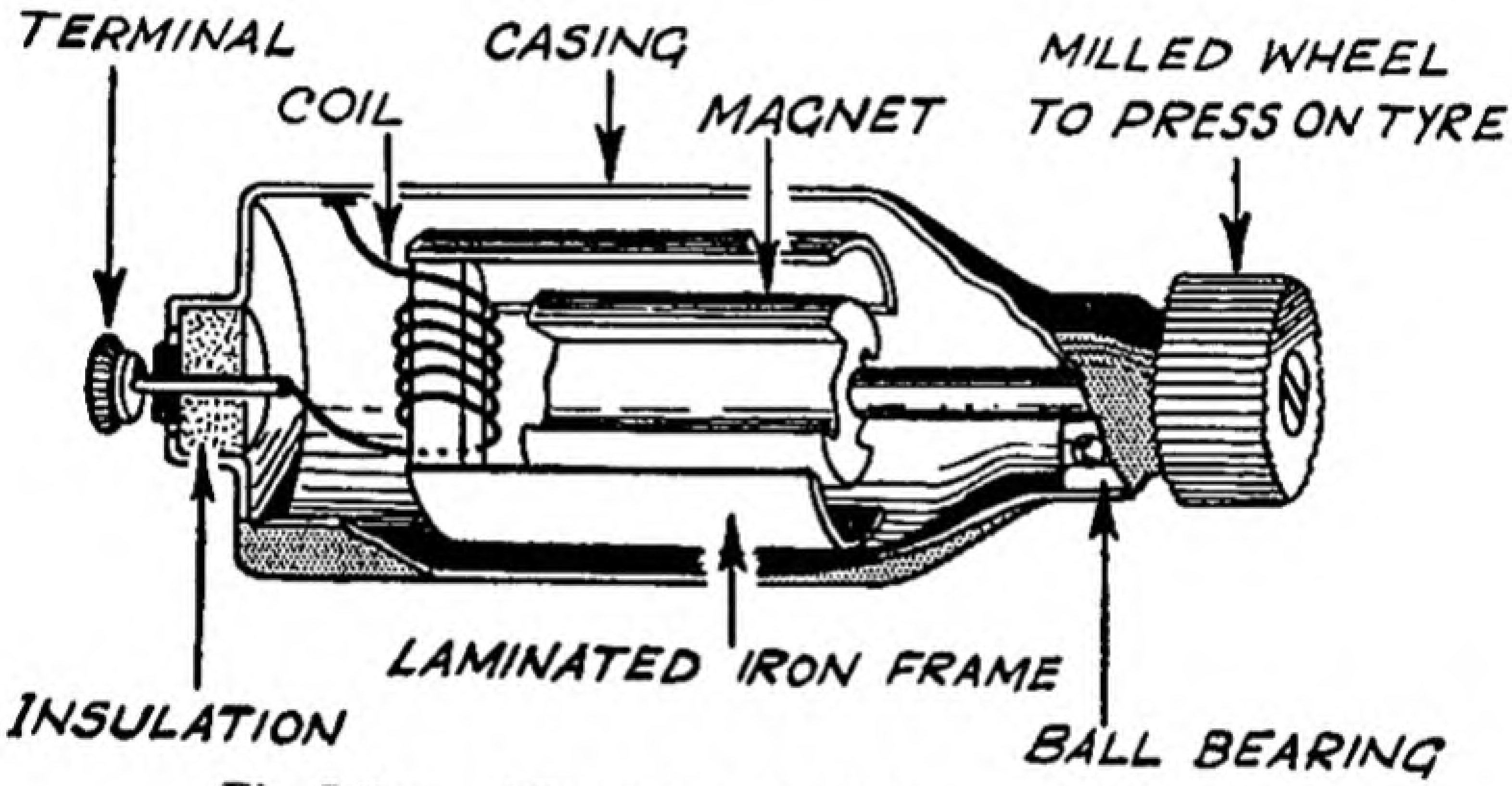


Fig. XI, 1.—The principle of the cycle dynamo

usually consists of a small permanent magnet armature, revolving between the poles of a magnet frame on which the coils are wound (Fig. XI, 1). In this way there need be no contact with the moving part, and brush and slip-ring troubles are avoided.

The machine is usually fitted with ball bearings and normally needs no maintenance except an occasional drop of oil in the oil holes provided. It is driven by the milled wheel touching the tyre, when a spring bracket on which the dynamo is mounted is so adjusted that the right pressure is brought to bear. If the pressure is too great, the tyre will wear and the dynamo bracket will be strained. If the pressure is too light the dynamo may not run, and in slipping will also cause tyre wear. The correct angle for fitting the dynamo is so that the centre of the edge of the milled wheel forms a tangent to the rounded side of the tyre.

The dynamo provides about 20 volts on open circuit, when the bicycle is being ridden at any speed above about five miles an hour. It supplies the head-lamp and the tail-lamp, and usually a 12-volt 6-watt lamp is fitted in the head-lamp, and an ordinary 12-volt flash-lamp-type bulb in the rear light. The dynamo voltage is rapidly brought down to 12 volts or less when the load is applied, due to the impedance of its windings and the relatively inefficient method of generation.

Certain types of dynamo head-lamp employ two bulbs and have room for a battery so that when the cyclist is riding in dense traffic the lights will not go out every time he stops. A change-over switch enables him to supply a smaller head-lamp bulb and the normal tail lamp from the battery.

One of the main causes of trouble with dynamo lighting systems relates to the return-circuit path, which is made through the frame of the bicycle. The clips used to hold the head-lamp on the handlebars or on the front fork do not always make good contact with the metal of the machine, which is coated with a strong layer of enamel. Special pointed screws are usually provided to penetrate this enamel and so make effective contact, but in spite of this there are many occasions when dynamo lighting systems are put out of order for this reason. The only completely certain cure is to use twin wire in place of the single wire usually employed, and to run the return current connection independently of the frame, directly from the two lamps back to a suitable screw or bolt on the dynamo body.

Automobile Electrical Equipment

In automobiles, motor-cycles and motor-boats, the usual arrangement of the electricity supply system is that the engine drives a dynamo, on cars usually by means of a pulley round which the fan belt is made to run, and this dynamo feeds current through a voltage regulator and thence to a battery, which supplies the lighting circuits and the power for the auxiliaries such as the horn, windscreen wipers, car radio, heater, and the like, and also feeds current to a separate starter motor to start the engine.

The dynamo is thus driven at a speed that varies with the engine speed. In the case of motor-cars especially, the engine speed may vary between zero and perhaps 5,000 r.p.m. The dynamo is basically of the shunt type and if no voltage regulation equipment was provided its voltage would vary within very wide limits as the speed varied. This would cause two difficulties: first, the battery would be excessively

charged at high speed; and secondly, the lamps would rapidly burn out if subjected to high voltages.

One of the most widely used control systems, which has been employed for very many years, is the third brush. In an ordinary two-pole dynamo, if the poles are considered as being horizontally disposed with the armature between them, the full voltage at no load is available from brushes placed on the armature at points vertically above and below the centre line (Fig. XI, 2). When current is drawn the armature itself becomes an electromagnet and the flux produced interacts with the flux from the stationary poles, and so distorts the resultant flux through the armature that the proper position for the brushes is no longer vertically up and down above the centre

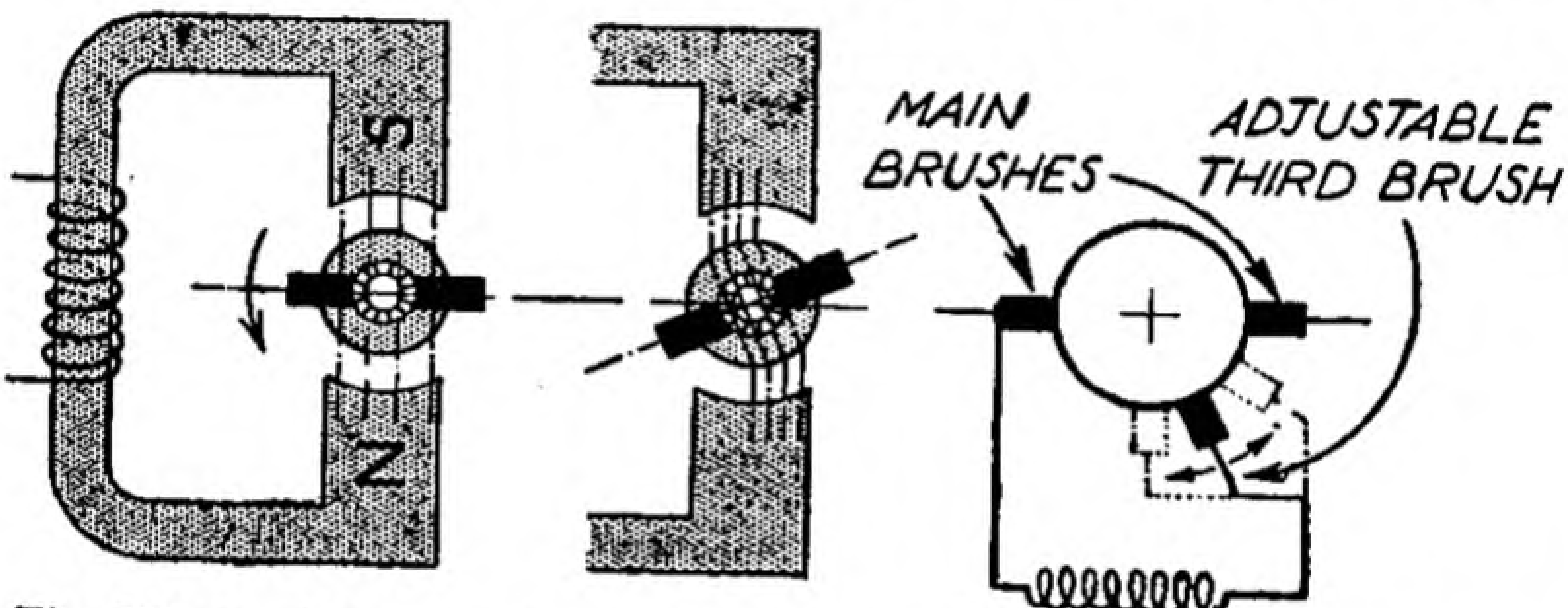


Fig. XI, 2.—Diagram illustrating the third brush voltage regulation principle

line, but on a line displaced by an angle of perhaps 10° or 20° from it (Fig. XI, 2). The greater the current, the greater the displacement from the normal neutral position. The voltage output depends on the strength of the field and if the field is fed from the dynamo itself the effect of armature reaction, as this displacement of the neutral position is called, may be used as a form of automatic current control.

Three brushes in all are provided, two main brushes for the load circuit being placed on a line so far displaced from the neutral position as to provide proper commutation and full output at the normal rated current, and a third brush is placed between the others and usually adjustable as to exact position (Fig. XI, 2 (*right*)). The field is connected to one of the main brushes and to this third brush.

If the current increases, the proportion of voltage available to the field winding will decrease as the armature reaction effect lessens the voltage at the third brush position. In this way a considerable degree of automatic control is provided; and this is known as the constant

current system, since it depends for its action on control of current. By moving the third brush-holder in the direction in which the armature is running the current output can be increased, and by moving it in the other direction the current output can be decreased.

The second method of control is known as the compensated voltage system and takes the form of an external regulation of the field current of the dynamo, thus regulating its output. In the simplest system, the field circuit includes a resistance which can be short circuited by means of a contact which is operated by means of an electromagnet

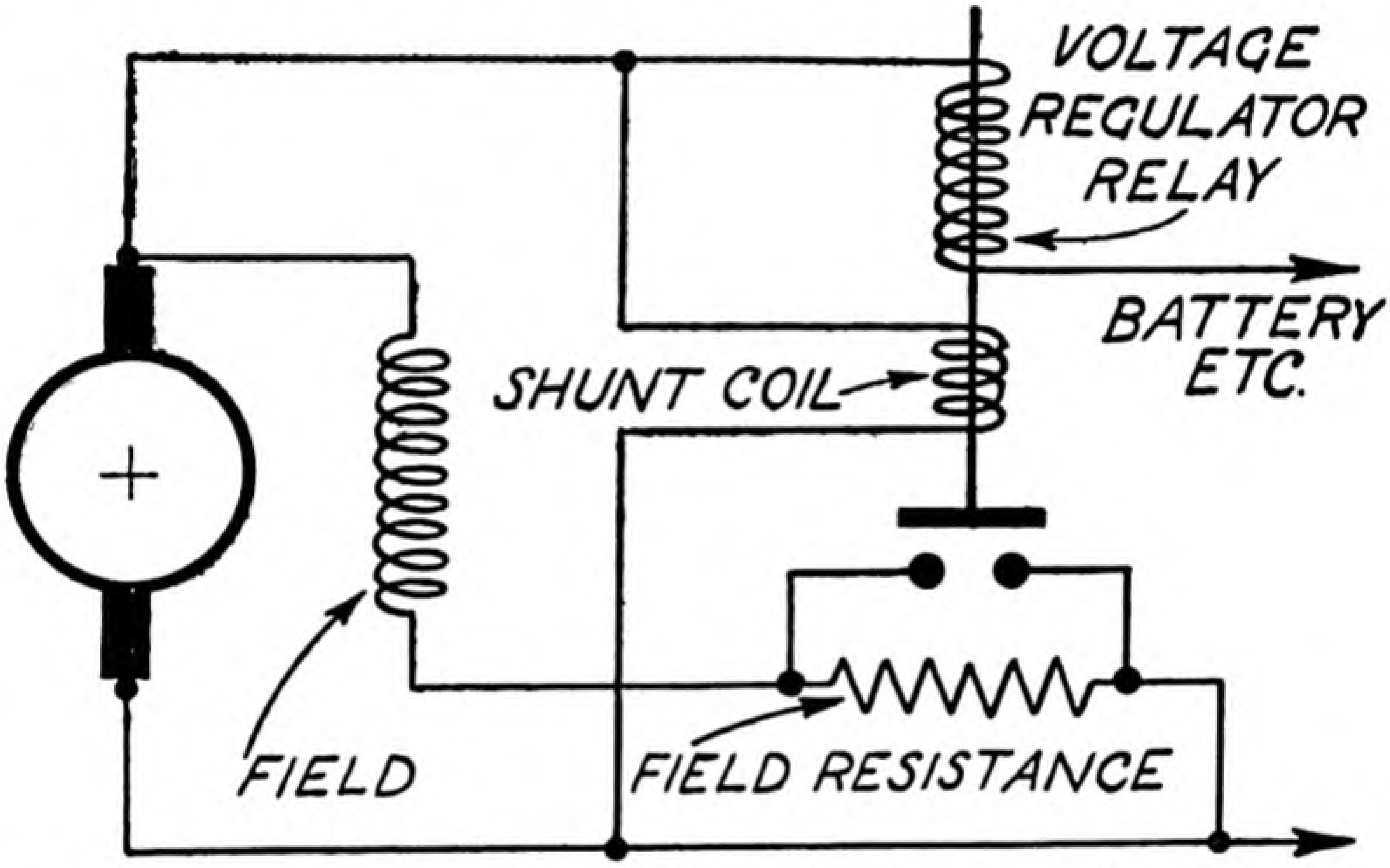


Fig. XI, 3.—The principle of the voltage regulation circuit used on motor vehicles

whose coil has two windings, one in series with the main output current from the dynamo and the other shunted across its terminals (Fig. XI, 3).

When the dynamo is started, the resistance in the field circuit is normally short circuited, so that the maximum field current can flow. As the voltage rises, the current in the shunt coil connected across the dynamo output will also rise and will energize the electromagnet so that the shunting contact across the field resistor is opened, and the resistance will be inserted in the field circuit so reducing the field and in consequence the dynamo voltage. As the voltage drops, the electromagnet current falls, the armature drops off and the contact is made once more. This sequence of operations may take place as often as 60 times a second and in this way the dynamo voltage output is kept within close limits.

If a car battery is in a discharged state the current supplied from a constant voltage source would be very high and to meet this difficulty a second winding on the electromagnet, in series with the output current, is usually provided. This winding has the effect of lowering the voltage (and consequently the current), if the load is too great, by overriding the action of the shunt coil and opening the short-circuiting contact of the field resistance more frequently. A final compensating feature is the provision of a bi-metal strip (not shown in Fig. XI, 3), heated by means of a small winding in series with the shunt coil, which is mechanically so arranged that as it bends it alters the tension of the spring controlling the short-circuiting contact and thus affects the degree of regulation provided. As the dynamo warms up the current tends to vary, but this bi-metal strip compensates for temperature change.

Another voltage control system commonly employed is the carbon pile regulator. Here the resistance in the field circuit, which controls the voltage, is not in the form of a single step of resistance control as in the previous case but consists of a pile of carbon discs pressed together by means of a spring. As in the case of the telephone microphone, the resistance of a number of carbon objects under pressure varies with the pressure and this effect is made use of in the carbon pile regulator. The electromagnet, with its series and shunt coils, is so arranged that its armature presses on the carbon pile and alters its resistance according to the degree of pressure exerted. In this way a continuously varying degree of regulation is provided and the need for a contact that is continually opened and closed is obviated.

The Cut-out

The next component to be considered is the cut-out. Obviously, means must be provided whereby the battery cannot discharge itself into the dynamo when the dynamo voltage is below that of the battery, or (when the engine is at rest) when the dynamo voltage is zero. The cut-out, or reverse current relay, takes the form of a series coil, in series with the load current, and a shunt coil across the dynamo, both wound on the same magnet frame, but in opposition (Fig. XI, 4).

When the dynamo begins to generate voltage, the spring holding the cut-out contacts open will be overcome by the attraction exerted by the shunt coil, connected across the dynamo output, when a voltage figure is reached which is slightly greater than the normal battery voltage. This may be of the order of 14 volts on a 12-volt system and about 7·5 volts on a 6-volt system. The circuit is then made, and

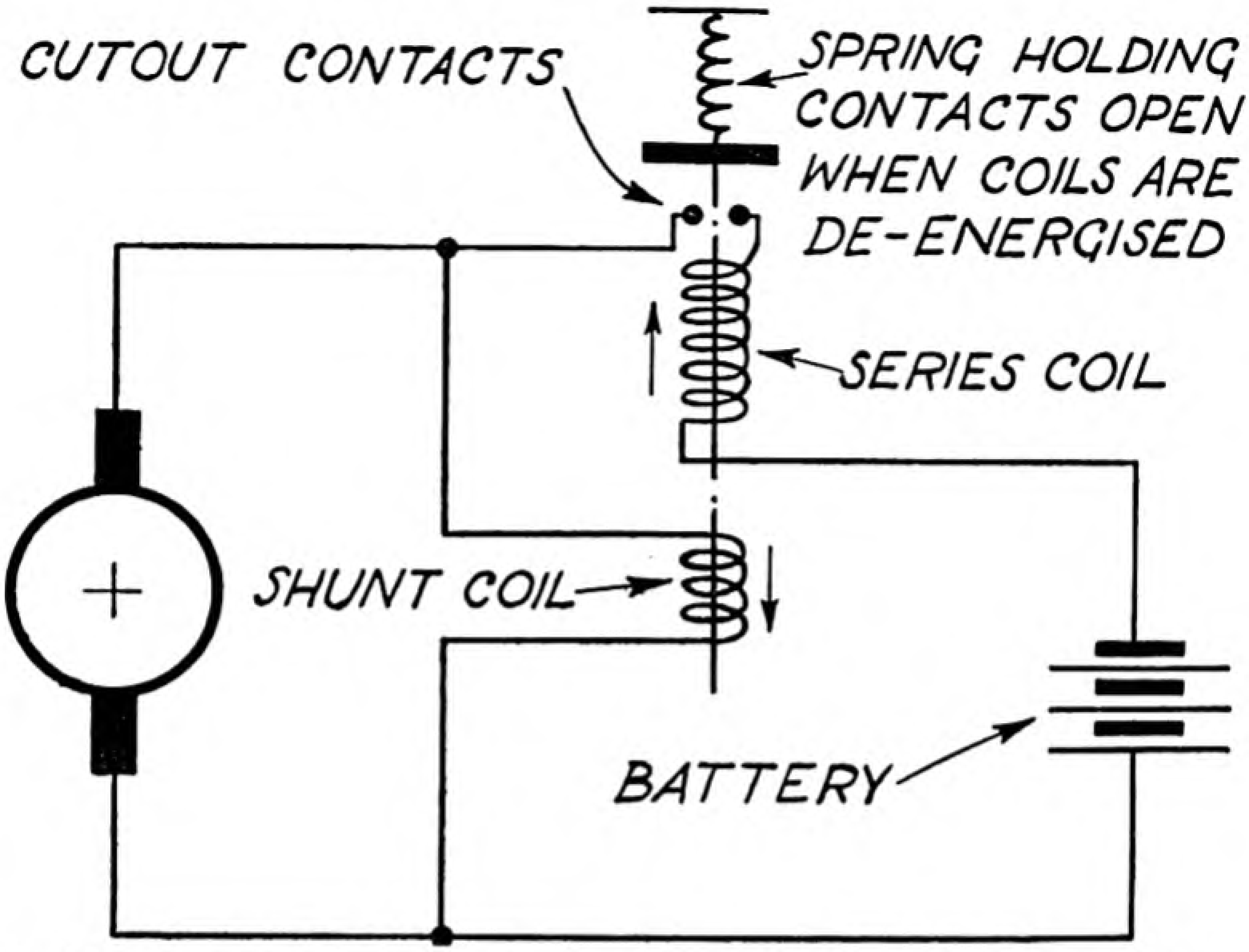


Fig. XI, 4.—The cut-out, as used on automobile electrical systems to prevent the battery discharging into the dynamo

current can flow, but if any current tends to flow in the reverse direction the reversal of the flux produced by the *series* coil will cancel the flux produced by the shunt coil, and the spring can then pull open the contact, breaking the circuit and preventing reverse current flow. The power supply side is completed by a fuse or fuses, as one main fuse is fitted in the dynamo circuit, and there may also be a fuse in the field circuit.

Dynamo Maintenance

The maintenance of the dynamo should include periodic inspection of the brushes and commutator. This latter should be a golden brown in colour and when cleaning it glass paper and not emery paper should be used. If the mica separators between commutator bars have risen above bar level, they should be cut down with a fine hack-saw blade so that they are just below the surface of the adjoining segments. The brushes must be replaced when they are worn, and should ride easily in the brush-holders. The flexible pigtails which connect them to the terminals should be carefully arranged so that they do not form short circuits, either to frame or to the adjacent brush. All carbon dust should be removed, as this may eventually

lead to short circuits. Carbon tetrachloride, being non-imflammable, is the best cleaning substance to use for this purpose. The bearings of the dynamo need a few drops of oil at long intervals, but oil must on no account be allowed to reach the commutator.

Most car and boat electrical systems operate at one of the two standard voltages, 6 volts or 12 volts, and dynamos give about 15 amperes at 6 volts or 20 amperes at 12 volts. The choice of output voltage is usually made on the score of cheapness of the battery, and thus the smaller cars use the 6-volt system and the larger cars 12 volts.

It was mentioned earlier that the scale effect was one of the problems of designers of electrical equipment for moving vehicles. If the design of, say, a 20-h.p. motor or 15 kW dynamo is carried out on the drawing board according to the best theoretical rules, the sizes of all the parts concerned can be calculated exactly and a high degree of theoretical and practical efficiency can be obtained. If the designer then chose to use the same calculation methods to produce a machine a tenth of that size, he would immediately run into difficulties. One of the obvious difficulties concerns the size of wire (and the dimensions of its insulation) to be used for the field coils. It is not practicable, for mechanical reasons, to employ wire smaller than a certain degree of fineness, and moreover the thinnest layer of enamel for insulating purposes has an irreducible thickness. Thus he would find that he could not employ the number of turns in the field winding that his theoretical calculations had called for, and a number of compromises would become necessary. The effect of these compromises would be to produce a machine not inferior from the point of view of reliability but one of lower efficiency.

The compromise necessary in the design of the car dynamo may be illustrated by some typical figures. A 15-ampere, 12-volt dynamo provides 180 watts on the output side. Theoretically, 746 watts equals 1 h.p., and therefore this output should need about one-quarter of a horsepower. But in all dynamos there are the field excitation losses, the friction losses, and the iron and copper losses to account for, so that an efficiency of about 75 per cent may be expected. This would mean that one-third of a horsepower would be needed. In practice, the dynamo indicated would draw nearly one whole horsepower from the engine when delivering its full output.

The Accumulator

The third problem is that of storage of energy. Here there is only one possible method—the use of the storage battery, which is generally of the lead-acid form but may be of the alkaline type.

Practically all the electrical equipment of a car or boat is light, robust, and requires practically no maintenance for long periods. It is not greatly affected by heat or cold. The battery shares none of these advantages. No way has yet been found by scientists to store electrical energy other than by the use of the electrolyte container with its relatively heavy lead plates. The weight of a 6-volt lead-acid battery may be of the order of 50 lb., which is a not insignificant proportion of the weight of the whole car, and the 12-volt battery, which is more widely used, may weigh about one and a half times as much. The container, usually made of strong plastic, is still vulnerable to mechanical damage. The acid level needs regular inspection, and topping up with distilled water. Corrosion round the terminals frequently occurs. When temperatures of near zero Fahrenheit are reached, the current output of the battery, for starting a cold engine, is reduced by nearly 50 per cent.

These criticisms of the storage battery are not intended to convey the idea that the manufacturers have been in any way unprogressive. Everything humanly possible to improve the storage battery has been achieved and research is continuous; but nevertheless the battery forms a cumbrous and awkward item in the electrical equipment of a car. It is the best that science can provide so far.

Battery maintenance consists of maintaining the acid level and ensuring that the specific gravity of the acid is kept within the limits specified by the makers. This figure is checked by means of a hydrometer, which comprises a glass pipette with a rubber bulb at one end and a flexible rubber pipe at the other. Inside is a graduated float, with a mercury or lead weight counterbalance in the lower end. The rubber tube is inserted into each cell of the battery in turn and a small quantity of acid is sucked out. The float will swim in this acid and will indicate, by the graduations on its face, how far down it goes. This will be proportionate to the gravity of the acid, which should be of the order of 1·250. If the acid level falls too low or if the battery is allowed to stand for long periods without charge or discharge it will be seriously damaged. It may also be damaged by freezing. The terminals should be kept clean, and once all corrosion has been removed they should be wiped over with vaseline.

Engine Ignition

The most vital application of electrical energy in the automobile, and on board small boats, is the provision of a means of ignition for the engine. In the case of the diesel engine, now used increasingly

for all but the smallest-sized units, no ignition equipment is necessary.

In the early days of internal combustion engines, the spark energy for the spark plugs was provided by means of a magneto, and this device is still used in special applications, and in most marine and piston-type aero engines. The magneto consists of a permanent magnet frame, usually made of high-permeability magnetic material such as aluminium-nickel-cobalt alloy, within which a wound armature is made to rotate. There are other types in which the permanent magnet revolves, and the windings are stationary or both may be stationary with a rotating sleeve between them. In all cases the basic principle is the same. The current generated is a.c., and the transformer effect is used to step it up from the generated voltage to the figure of about 5,000 to 15,000 volts needed by various types of sparking plugs. At the end of the magneto shaft is a contact breaker, which is connected in series with the primary (low-voltage) winding, and is arranged to break the circuit at the appropriate moment when the voltage induced in the secondary winding will be a maximum. To prevent arcing at the contacts, a capacitor (previously known as a condenser) is connected across them, to absorb the arc energy. The high voltage impulses generated by the opening and closing of the contact breaker are distributed to the various sparking plugs by a distributor, whose central arm is also driven by the magneto shaft.

The most widely used system of ignition at the present time is that which employs a coil, taking current from the battery. The "ignition coil" is in fact a transformer, and direct current from the battery is taken to its low voltage winding through a contact breaker driven from the engine shaft. The interrupted current in the primary operates in the same way as if it were alternating current and produces a high voltage in the secondary winding and this voltage is taken to the distributor, which is usually combined with the contact breaker in one assembly. From there it is distributed at the right moment to each plug. A capacitor is used across the points of the make-and-break as in the case of the magneto (Fig. XI, 5).

Very little maintenance is required by a modern ignition system. The points of the make-and-break device must be kept clean and properly adjusted as indicated by the makers. A rough and ready guide to the distance between the points is that they should, when fully open separate by about the thickness of a thumbnail.

The distributor usually takes the form of an inverted cup of plastic material, which fits over the make-and-break device, and which has four (or six) sockets round the outside into which the high tension

cables to the plugs are fitted. In the centre of the inside of this inverted cup is a small spring-loaded carbon brush, which serves to connect the high voltage lead from the coil to the top of the revolving rotor arm, and this brush may become worn, resulting in a failure of the ignition system. The spring should be handled very delicately. The inside of the cup is liable to become somewhat dirty, owing to slight wear on the carbon brush, and it should occasionally be given a thorough clean.

The moment at which the spark occurs in any particular cylinder

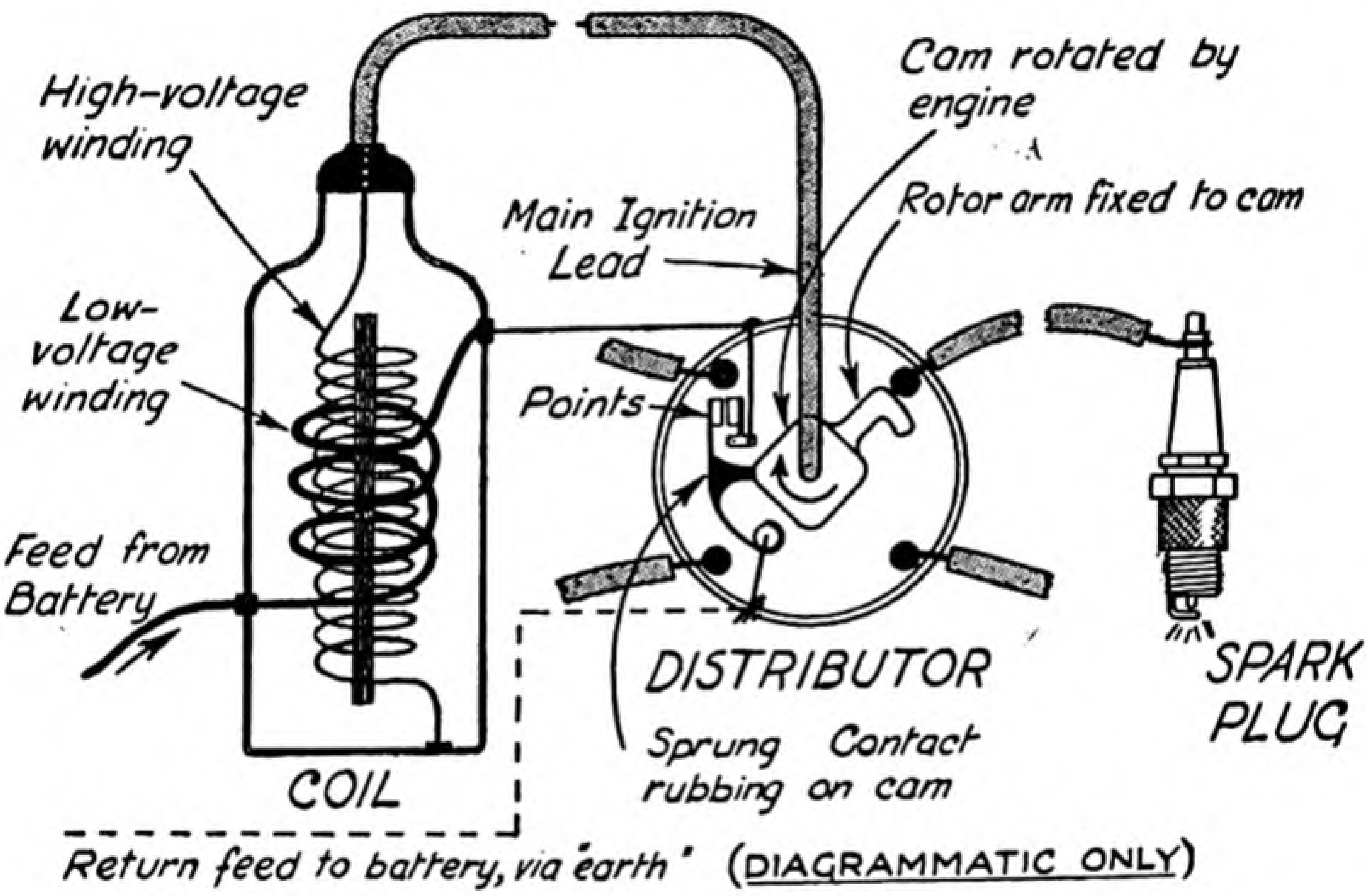


Fig. XI, 5.—The principle of the coil ignition system

is of vital importance to the performance of the engine. As the engine speeds up it is usually found desirable to "advance" the spark so that it fires at an earlier position in the cycle carried out by each piston. This is achieved automatically by pivoting the body of the make-and-break device, so that it can move through a slight angle and can be operated by a suction piston connected to the induction manifold of the engine. When the engine runs faster the decreased suction operates on a plunger to rotate the make-and-break device and so advance the ignition point in the cylinders.

In the future it is likely that electrostatic ignition systems may be widely used. Already in America electrostatic generators have been applied to cars. The principle of the electrostatic generator derives

from the very earliest electrical experiments, carried out perhaps 2000 B.C. When a piece of amber is rubbed on a catskin, sparks can be drawn from it, because the friction effect sets up an electrostatic charge on the insulator, in this case the amber. A similar effect can be obtained when removing a dry silk garment. The electrostatic generator employs an insulated cylinder driven round by the engine. It becomes charged by induction, and transfers its charge to a fixed insulating electrode where the charge collects until a high voltage is reached. In this way, the losses of energy that occur in the electromagnetic circuits of a coil are avoided, and a much more powerful spark is produced.

Radio Interference

The reduction of radio and television interference from car ignition systems is nowadays essential, and may be carried out in several ways. The simplest method, which is reasonably effective, is to instal a resistance in the main lead from the coil to the distributor. The spark plugs act as small untuned generators of radio waves, and the high resistance inserted in the lead cuts down the value of the high-frequency current to a negligible amount without appreciably affecting the performance of the engine. For complete shielding it is necessary to instal tuned filter units in the ignition system, and to enclose all wiring in metal sheathing, carefully bonded to earth. In the case of aircraft engines, where it is vital that the radio and radar equipment should not be disturbed by engine interference, these comprehensive shielding measures must always be carried out.

Starter Motors

The starting of internal combustion engines is carried out by means of a special starter motor. In the past a combined dynamo and motor was often used, known as a dynamotor, but the complications necessary have tended to render it obsolete. The starter motor is of the series type, as only this design would give a powerful enough torque to turn a heavy engine against the compression in the cylinders. A very heavy winding, of a few turns, traverses the two poles in series with the armature, and since currents of the order of 300 to 400 amperes or more are needed to start a cold engine, the leads to the starter from the battery must be of very large section and as short as possible, otherwise the voltage drop in the leads themselves will be excessive. The starter motor runs at about ten times the speed necessary to crank an engine, which is about 30 r.p.m., and it is usually meshed

with a gear wheel on the outside of the engine flywheel, by means of a special pinion. This pinion, on the end of the motor shaft, is mounted on a helical screw and when the starter motor accelerates the pinion flies along this screw to the end of its travel, where it engages with the teeth on the flywheel pinion. When the engine fires and accelerates, the action of the flywheel—running proportionately faster than the starter motor—causes the starter motor pinion to disengage.

Occasional trouble is caused by the failure of the starter pinion to disengage, in which case the engine will stall. To remedy this, the starter pinion should be kept oiled, together with its helical screw; but if it does stick, most starter motors have a square end on the motor shaft which can be turned by means of a spanner and this will have the effect of freeing the starter pinion. Another method is to put the car into a forward gear and rock or push it backwards.

The maintenance needed by the starter is the same as that for any form of electric motor—normal attention to the brushes and commutator, and lubrication for the bearings.

Lighting

The lighting equipment on automobiles and boats is simple and the only point of electrical interest is the fact that most lighting circuits use a single wire only, as the battery positive is earthed and the return circuit is carried out through the frame of the car. This gives rise to difficulties on occasion, when rust surrounding the mounting of a side lamp, for example, prevents good contact between the lamp body and the frame of the car. This may be prevented by installing twin wiring throughout and in the case of boats this practice is common.

The lamps used are usually of the tungsten type, with S.B.C. (small bayonet cap) fittings of a special type, with a single contact. Thirty-six watt bulbs are used for head-lamps and fog-lamps and 6 watt lamps for parking-, tail- and side-lights. Certain types of head-lamp are made up of a sealed unit, comprising a glass bowl which contains a silvered surface inside as well as the actual lamp filament. By the use of this type of unit there is never any danger of the reflector becoming tarnished but if the lamp should be broken or if the filament burns out replacement is naturally considerably more expensive than in cases where the bulb is separate. The fuses of lighting circuits are usually arranged so that the blowing of one fuse will leave at least one light at the front and at the rear of the car.

Dipping head-lamps include an electromagnetic device which may be arranged in several ways but which usually switches off the

offside lamp and physically swings the nearside lamp over so that the beam is deflected downwards and towards the nearside kerb.

Other Auxiliaries

Some cars and boats are equipped with electrically driven petrol pumps. In general such pumps employ a flexible diaphragm, which is moved up and down over a chamber equipped with non-return valves so that on the upward strokes petrol is sucked from the tank, the outlet valve being closed; and on the downward stroke the inlet valve is closed and the outlet valve is opened, allowing the petrol to flow to the carburettor. The electrical mechanism takes the form of a solenoid of which the plunger works the diaphragm and which is equipped also with a spring return, and with electrical contacts ranged similarly to those of an electric bell. When battery current is fed to the solenoid it makes a stroke to pull the diaphragm upwards and in doing so breaks the contact in its own circuit so that the spring forces the diaphragm backwards on the return stroke. The process is then repeated. The only maintenance necessary is the periodic cleaning of the contacts if they should become pitted.

Direction indicators employ solenoids and lamps. The solenoid coil is energized from the battery circuit and draws in a plunger which lifts the indicator arm and at the same time closes a pair of contacts which feed a small lamp placed behind the plastic sides of the indicator. The circuit of the indicators is often led through a switch on the steering wheel in which is incorporated a mechanical device so that once the wheel has been turned in the direction relating to a particular indicator, the circuit is automatically broken. The maintenance of traffic indicators requires an occasional drop of oil on the solenoid linkage and cleaning of the contacts if the lamp fails to light. An alternative, widely used on the Continent and now legal in Great Britain, is the flashing lamp form of direction indicator. In the lamp circuit is a bi-metal strip and a small heater, which causes the strip to curl and break the circuit, resulting in the heater cooling down and allowing the bi-metal strip to make the circuit once again.

Car heaters and air-conditioners employ a radiator through which hot water from the engine cooling system is circulated. Behind the radiator is situated a small fan driven by a motor of the series type, whose speed can often be regulated by means of a rheostat inserted in the circuit.

The horns used on cars and boats are of the type mentioned in the chapter which deals with bells (p. 223). The horn may draw a

heavy current of as much as 10 to 15 amperes, and thus to prevent undue wear on the contacts of the horn button itself, a relay may be incorporated in the circuit.

Windscreen wipers are actuated by small electric motors operating through gearing and oscillating mechanism. These motors are of the series type and therefore employ commutators and brushes; they need occasional cleaning and oiling.

Car radio units draw a considerable current from the battery, sometimes as much as 5 amperes, and as they may be in circuit for long periods it is usual to step up the generator output when a car radio set is fitted, so as to allow for the additional load.

The general limiting factor on car electrical equipment is the parking load. Dynamos can be provided to deal with all the lighting, ignition, pumping, etc., demands during running in such a way that the battery is "floating" on the system or drawing a small charge. With the various legal requirements for lighting now demanding twin tail-lamps as well as two lamps at the front of the car, the battery has to be larger and consequently heavier.

Aircraft Equipment

The supply of electric power on board aircraft involves a somewhat different set of requirements from those which apply to cars and boats because the loads are so much heavier and more vital, e.g. actuation of controls and such items as landing gear; radio and navigational services; pressurization, including air-conditioning; and cabin services such as lighting and heating.

In all a large modern aircraft may need up to 30 or 40 kW of auxiliary power. This is provided by generators driven from the main engines and modern jet or turbo-prop engines have auxiliary gear boxes fitted from which the generators can be driven. In jet engines the generator might be directly driven from the shaft and may be situated in the compressor intake, where it is cooled by the incoming air.

There are certain aircraft in which small gas turbines are provided to drive generators separately from the main propulsion units.

In either case the systems of auxiliary power supply may be one of two types. Earlier aircraft installations employed 24-volt direct current generators but in recent years there has been a tendency to employ a.c. generation, and since some of the equipment to be driven by electric power, such as actuators or the aircraft control services, needs very small motors running at high speeds, the advantages of high

frequency three-phase a.c. operation have been secured by using three-phase generators delivering power at 400 c/s and about 110 volts. Some of the output is rectified by using dry-plate rectifiers, but for the feed to radio components and navigational equipment the a.c. supply is found to be more convenient.

One of the advantages of the a.c. system is that the generators do not need to be equipped with brush gear. This feature, on d.c. generators, has been a source of trouble since at high altitudes brushes are found to spark much more than at sea level. This phenomenon is due to the decrease in air pressure.

A.c. generation suffers from the disadvantage that variation in engine speed produces a variation both in voltage *and* frequency; but d.c. generation also suffers from varying voltage and it is necessary to provide complicated, heavy and cumbersome voltage regulation equipment.

The demands for power will vary from aircraft to aircraft, depending on whether most of the control surfaces are operated hydraulically or electrically. The variable pitch propeller controls in piston and turbo-prop engines, landing gear operation, and the operation of the actuators for the various control surfaces, may require as much as 45 h.p. per hundred tons of aircraft dead weight, although the power is required intermittently. If complete electric control is used, the generators will obviously have to be larger than those now generally provided, where a combination of electric and hydraulic controls is usually employed.

De-icing is usually carried out thermally but there is a tendency towards using electrical operation, as on the whole it may be made more efficient by using short bursts of heating to detach ice layers, whereas thermal de-icing cannot be so easily controlled and much heat is wasted. For propellers, electrical heating is always used and about 3 kW per blade has to be employed.

Radio and navigational aids tend to increase in number and complexity, and most large modern aircraft need about 5 kW of power for this purpose. Cabin pressurization needs about 1½ h.p. per person when both heating and refrigeration of the air supply are needed. Lighting and cooking services on airliners need up to about 12 kW of power.

Generators for Aircraft

Aircraft generators have been developed along lines that differ considerably from designs used for generators for normal stationary service. The designer of any electrical machine must reach a

compromise which satisfies a number of conflicting requirements. Among these requirements are extreme reliability, high over-all efficiency, considerable intervals between maintenance periods, low weight, small over-all dimensions, and minimum cost. In the case of most generators for ordinary use, the weight is not of the greatest importance, and the dimensions are not regarded as critical. The aircraft electrical equipment designer has to cut down the weight to the last ounce, and in doing so he generally arranges for the machines to run at higher speeds and higher potential temperatures, so as to obtain greater output from a given size, and weight of machine. To counteract the high temperature rise, he has to arrange for the generators to be cooled by a continuous blast of blown air.

It is interesting to see (as the present writer has on a number of occasions) the testing of a 20 kW aircraft generator. It is driven by a normal stationary motor, of a size equivalent to 20kW, through gearing, and the stationary motor looks about seven or eight times as large as the aircraft generator at the same rating.

It is usual to provide complete duplication or even triplication of supplies and this is usually achieved by providing, say, four generators, one on each engine, any one of which will carry the whole load for a brief period as an overload condition, any two being normally used to supply the aircraft's auxiliary requirements. Automatic change-over switches are provided so that if one generator fails another is switched on instantly.

ELECTRIC TRACTION

Turning now to the consideration of electrical equipment on moving vehicles where electrical energy provides the tractive effort, we distinguish three classes: those in which electrical energy is stored on the vehicle; those in which it is generated on the vehicle; and those in which it is brought to the vehicle by means of contact with some form of pick-up wire or rail. There are in practice only two types of vehicle in which stored electrical energy provides the main motive power, these being the battery vehicle and the so-called gyrobus.

The gyrobus is only in the experimental stages, and may be briefly mentioned first. It is a Swiss invention, and the source of motive power is a heavy flywheel disposed horizontally (the axis being vertical) and driven by an electric motor which receives its energy when the vehicle is stationary, by being plugged in to a convenient power point. The mains supply is then used to accelerate the flywheel

until it is running very fast, and a considerable quantity of energy is stored up. The mains plug is then removed, and the motor becomes a generator and supplies power to the traction motor, or motors, to drive the wheels. The principle has been successfully employed for public service buses which can be run for 20 or so miles at normal speeds without "recharging". In practice two or three minutes is all that is necessary to acclerate the flywheel once more, by plugging in to power points situated along the route. This method of storing energy—in a rotating flywheel—is obviously of limited application but it is used for transport in factories especially where there is a big fire risk and also for starting big i.c. engines.

The more usual method of storing energy on board a vehicle is to employ a lead-acid or alkaline storage battery. The well-known battery vehicles, used in vast numbers to distribute milk, bread and similar commodities in urban areas, usually employ a 200-ampere-hour battery of 50 volts, driving a single traction motor, of the series type, running at about 2,000 r.p.m. and driving the road wheels through worm gearing. Speeds of about 20 miles an hour may easily be attained, although pedestrian-controlled delivery vehicles are arranged to run at not more than 3 or 4 m.p.h. The motor may be of 10 h.p. rating for a 10 cwt. vehicle, but its size will vary with the type of duty required. The control of speed is obtained in several ways, but for the smaller vehicles the insertion of series resistances, cut out in steps by means of a drum-type controller, is all that is necessary. For larger vehicles the field windings of the motor may be arranged in sections which are cut out as required by the use of contactors, operated from the controller.

In most cases the owner of a fleet of vehicles will purchase a number of spare battery units, which can be charged by taking advantage of cheap-rate tariffs at off-peak hours during the night. The battery containers are arranged so that a discharged battery can be slipped out on rollers and plugged into the charging board with the minimum of effort, and in a few moments a new battery can then be inserted so that the vehicle is never held up. Every vehicle is fitted with a "state of charge" indicator, which shows the driver how far the battery has been discharged.

Types of vehicles in which the electrical battery storage principle is employed include factory trucks, such municipal vehicles as refuse collectors and tower wagons for the repair of street lighting equipment, and invalid carriages. A few private cars are also produced each year, for special purposes, with battery power.

Some battery-powered boats are used in pleasure gardens, on small rivers, and for special duties in the Services. For many years

submarines had to use the battery as the source of motive power when submerged but nowadays the "snort" enables them to run their diesel engines if they are only submerged for a shallow depth; below that level the battery still has to be used.

Battery shunting locomotives are used in power stations and also below-ground in mines, and a few main-line locomotives on electrified systems are equipped with batteries to enable them to carry out shunting duties on tracks away from the electrified main lines.

In the second of the three categories mentioned above we have the type of vehicle where power is generated by a prime mover driving a generator on the vehicle. There have been petrol-electric cars and buses, but the outstanding example of this class of traction equipment

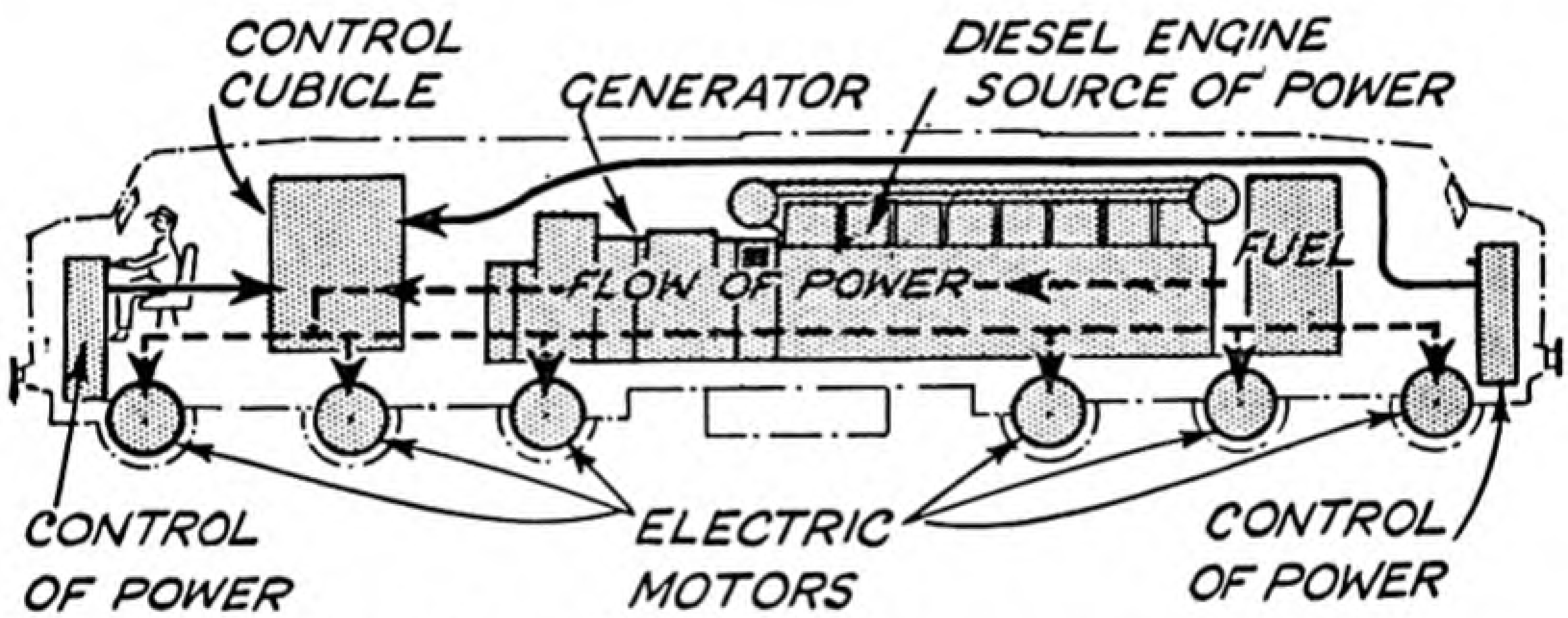


Fig. XI, 6.—The elements of the diesel electric locomotive

is the diesel-electric locomotive (Fig. XI, 6) or the steam turbo-electric ship.

In the diesel-electric locomotives, diesel engines, which vary in power from 300 to 2,000 h.p., are mounted on the locomotive to drive d.c. generators which in turn feed two, four or more traction motors. The reason for this energy transformation arises from the inherent difficulty in transmitting power from an internal combustion engine, which must at all times run at a relatively high speed, to the wheels of a locomotive. The engine employed on the ordinary motor-car needs a clutch and a gear-box for this purpose. These devices could only be employed for the smaller types of locomotives, and indeed are used for engines of up to about 100 h.p. Above this h.p. hydraulic torque converters can be used but they tend to be inefficient and large in size.

The diesel-electric transmission system provides for smooth take-up of the load and gradual speed control over the full range, since electrical control of the generator exciter, which supplies the field circuit,

gives perfect smoothness and a high efficiency of transmission from rest to full speed. Moreover, two or more diesel-electric locomotives can be coupled together, as is common practice in America, and by means of suitable wiring between them one driver can control all the locomotives. Automatic equipment can be provided so that the engine governor is coupled into the control circuits electromagnetically and can be adjusted so that at all times the engine is running at its most efficient speed, irrespective of the road speed of the locomotive.

Nearly a thousand diesel-electric locomotives are operating in Great Britain mostly for shunting duties, since their special qualities are here seen to best advantage. A steam engine, while shunting, is consuming coal even when it is not performing any useful work; and the normal shunting engine spends between 80 and 90 per cent of its time standing idle. The diesel-electric locomotive is instantly available and does not need four or five hours' preparation. It needs little water; it does not emit a dirty smoke; and it can be driven by one man. In America it is used almost to the exclusion of the steam locomotive on all the principal main lines.

The gas turbine has also been used as the prime mover for railway locomotives on the Continent, in Great Britain and in the U.S.A., the basic method of transmission of power being the same as that for its diesel-electric counterpart.

Electrical energy is conveyed to the moving vehicle in the case of two classes of public transport equipment, constituting the third category. First there is railway electrification, and secondly the tram and trolley bus. Taking a broad definition of electric traction, the many cranes and transporters that receive their power from trolley wires might be included.

Electric Railways

The first electric railway in Great Britain was that which ran out across the sea at Brighton, and was known as the Magnus Volk's electric railway. The first quarter mile of this track was electrified on the 1st August, 1883, although as far back as 1835 Mr. Thomas Davenport, of Brandon, Vermont, U.S.A., had experimented with model railways in which electric power was used, supplied by primary batteries. Since the 1890 period, a large proportion of the tracks on the world's railway systems has become electrified. In countries where there is abundant electrical energy from hydro-power, as in Switzerland and Sweden, practically all the railways are electrified.

For many years electric traction developed by employing d.c. at

about 600 volts, fed to the locomotive by means of either an overhead wire or a third rail, the two track rails being used in each case for the return circuit. Power was taken from special generating plants, as the rotary convertors used to change the three-phase a.c. to d.c. operated more satisfactorily at 25 c/s per second than they did at 50 c/s. At sub-stations situated alongside the track, rotary convertors, usually associated with large lead-acid storage batteries, were employed. During the night hours the batteries supplied the power and assisted in meeting heavy peaks. Nowadays, automatically operated mercury-arc rectifier sub-stations are used and batteries are no longer needed.

The rolling stock can be divided into two headings: locomotives and motor-coaches.

The locomotives usually employ six or even eight electric motors, geared to the axles by reduction gearing and fed from a pneumatically operated pantograph which makes contact with the overhead wire, or from shoes sliding along the third rail. Control of speed is effected by means of series-parallel switching of the motors, so that first a pair of motors is connected in series across the supply, and thus half the total voltage is applied to each; then various stages of resistance are cut out by means of contactors; and finally the motors are switched into parallel so that each receives the full line voltage. Series type motors are always used, on account of their powerful starting torque. Reversing is carried out by contactor switching of the field or armature circuits. Regenerated braking is fitted in certain cases, so that the motors turn into generators and in sending power back to the supply line, exert a braking force proportional to the power delivered.

In the case of motor-coach equipment, a train is made up with a coach equipped with a driving compartment at the end and having motors on its axles; and then follows a trailer coach with no motors, a complete set of three perhaps being made up of a driving trailer equipped with no motors but having a driving cab. By the use of control wiring throughout the train, the train may be driven from either end, this obviating the shunting necessary at terminal stations when a locomotive is employed. The London Underground Railways use motor-coach sets, perhaps two sets of three coaches coupled together. They are also used on the Southern Region electric lines, on British Railways.

In the case of the London Underground system four rails in all are used, the return current being carried by the fourth rail instead of the track rails to allow for better track-circuiting facilities connected with the rapid headway and the need for extremely flexible signalling arrangements.

Many electric railway systems at present operate on the lines indicated above. There were, however, some very early attempts to use alternating current on the overhead-line conductor along the track and these were successfully and widely used on the Continent and in America. Until recent times, however, it was not feasible to provide an electric motor operating directly at 50 c/s and capable of speed control. The motor would of necessity have to be of the single-phase type, and the main problem was the commutation difficulties when using a series type commutator motor at this frequency. Thus a lower frequency, which might be 16 2/3rds c/s or 25 c/s, at 6,000 volts or up to 20,000 volts, was employed on the overhead contact wire. Step-down transformers on the locomotives reduced the voltage to 600 to 800 volts, which was a suitable figure for the traction motors.

The progress of electrification throughout the world has been hindered by capital cost, and a large item in this cost has been the expenditure necessary to provide the fixed installations and the contact wire equipment. The use of a higher voltage, whether a.c. or d.c., would reduce the current in the contact wire and would thus reduce its costs. With d.c., a voltage of 3,000 has been found to be the limiting figure, as no voltage transformation is possible on board the locomotive. Even at this figure, the voltage drop on heavily loaded lines is such that sub-stations have to be provided at very frequent intervals and in any case converting equipment is necessary. In most cases, as mentioned previously, the converting equipment is of the mercury arc rectifier type, which can operate at ordinary power frequency, and therefore supplies can be taken directly from the national power supply system at 50 c/s (or 60 c/s in America).

With a.c. systems the voltage limitation does not apply and voltages as high as 20,000 volts can conveniently be used. The higher voltage makes the contact wire much smaller in section, and it also means that sub-stations can be less frequent along a given length of track. The capital cost is therefore reduced, as compared to d.c. The frequency-changing problem, however, nullifies these advantages to a considerable extent, as frequency-changing equipment is both costly and complicated.

In Great Britain the major railway electrification schemes being carried out in the 1950s are all operated at 1,500 volts d.c. with overhead contact wires, but in 1953 the first of a series of experiments took place on the Lancaster-Heysham-Morecambe line on which the ultimate goal of electrical engineers was achieved, the use of 50 c/s supplies direct on the overhead wire at high voltage, so that electric railway supplies could be tapped into the national grid system by the aid only of isolating transformers. These transformers, which are in

any case static and need no attention and little maintenance, are necessary since one pole of the supply connected to the overhead wire has to be earthed where it is connected to the running rails for the return circuit, and it would be impossible to earth one pole of the public electricity supply system.

For many years, Continental engineers experimented with various means of using the normal 50 c/s supply current on locomotives. These experiments included methods of changing the single-phase current to three-phase current by the use of special motor alternators, with single-phase motors driving three-phase alternators. The alternators in turn supply three-phase squirrel-cage motors, which are ideal for traction purposes from many points of view, since they do not require any brush gear or slip rings. These experiments also included the use of rectifiers on board the locomotive and the employment of specially designed motors which can accept the 50 c/s supply. The French National Railways have undertaken large-scale experiments with these three types of locomotives; the British experiment mentioned above employs the rectifier type. A transformer on the locomotive steps down the overhead-line voltage, which may be 20,000 volts, to about 800 volts, and the current is then rectified and applied to ordinary d.c. traction motors. Speed control, which is always a major problem with a.c. motors, is achieved by varying the transformer ratio, using taps on the secondary side for this purpose.

Once the technical problems of using normal electricity supplies on the locomotive or motor-coach have been completely solved there is likely to be a considerable increase in railway electrification, since the cost will be greatly reduced. The spread of national electricity supply networks in most countries has meant that power is available wherever the railway engineer needs it, without it being necessary for him to embark on the high capital cost of generating plant and main transmission networks.

Trolley Buses and Trams

The final form of electric traction to be dealt with is the tram or trolley bus. In a large number of municipal transport systems the cleanliness, quietness and high acceleration of the trolley bus, together with its cheapness of running, have been found sufficiently advantageous to off-set the higher capital costs as compared to petrol or diesel buses.

The trolley bus usually employs a d.c. voltage of about 500 volts, and since there is no possibility of an earth return two contact wires

must be provided along the whole of the route. The two trolley arms terminate in grooved wheels which make contact with the two wires. The power is taken to a single motor, driving the two back wheels through reduction gearing and a differential, as in a motor-car. The main motor usually has attached to it a small auxiliary generator to charge a 24-volt battery for lighting purposes, and this battery is often arranged to be of sufficient size to allow for the trolley bus to be moved very slowly on battery power alone if the trolley arms should leave the overhead wire, or if the bus has to be shunted off the route due to road obstructions.

The supply for the trolley bus system is usually provided by mercury arc rectifier sub-stations, three or four usually being sufficient for a complete municipal trolley bus network.

The tram is not as much used in these days as formerly. It usually takes in a d.c. supply, at about 500 volts, from a single pantograph or trolley arm, the rails being used as the return path. The tram employs two or more motors, speed control being carried out by means of series-parallel control and series resistances, cut out in steps as the speed increases. Trams are sometimes equipped with electromagnetic brakes, whereby a shoe is arranged to run immediately above rail level, and this shoe contains an electromagnetic coil which can be energized for an emergency stop. When this is done, the shoe is attracted strongly to the rail and so pulls the tram to a standstill very rapidly.

CHAPTER XII

TELEPHONES AND BELLS

THE electric bell is a very simple device and takes two forms, one for direct current (although it can usually be used on alternating current) and the other suitable for alternating current only.

The trembler bell (Fig. XII, 1) is made up of an iron frame, usually of horseshoe shape, on which there are two coils, thus making it into an electromagnet. Across the poles of this electromagnet is an iron armature held by a flat spring, so arranged that it normally rests against a fixed contact. At the end of the armature is a wire terminating in a hammer, which strikes the gong. The power circuit is taken first through the coils, then to the fixed contact and from this through the armature, which is insulated from the electromagnet itself, and so back to the other pole of the supply. When the power is switched on, usually by closing the bell-push, the circuit is completed and the electromagnet attracts the armature. As it is attracted, the hammer strikes the bell or gong, and at the same time the connection to the fixed contact is broken, so that the circuit is broken, and consequently the electromagnet is de-energized. This causes the spring to pull the armature back against the fixed contact, with the result that the circuit is made once again, so that the gong is repeatedly struck by the hammer. The frequency of striking can be adjusted by altering the tension of the spring holding the armature and by adjustment of the fixed contact. The only maintenance normally required by the electric bell is the cleaning of the contacts, or the adjustment of the contact screw from time to time as the contacts tend to pit due to the arcing which occurs every time the circuit is broken.

Bells of this type are often operated from dry batteries and usually require about two or three cells, giving about 6 volts. They may also be operated on alternating current by means of a small step-down transformer, which gives a voltage of about 10 or 12 volts on the secondary side, the primary side being connected to the 240-volt mains through

special light fuses. With alternating current operating, the sparking will be greater every time the circuit is broken, because of the inductive effect of the coils.

For alternating current use, a buzzer type of bell is generally more suitable. This consists of a gong near to the rim of which is a very light spring armature, terminating in a brass knob at the end. Below this is a coil, connected either directly to the mains or to a step-down transformer, and there is a small air gap between the iron former of the coil and the iron of the armature. When the coil is energized, it becomes an electromagnet which is alternately north and south, as

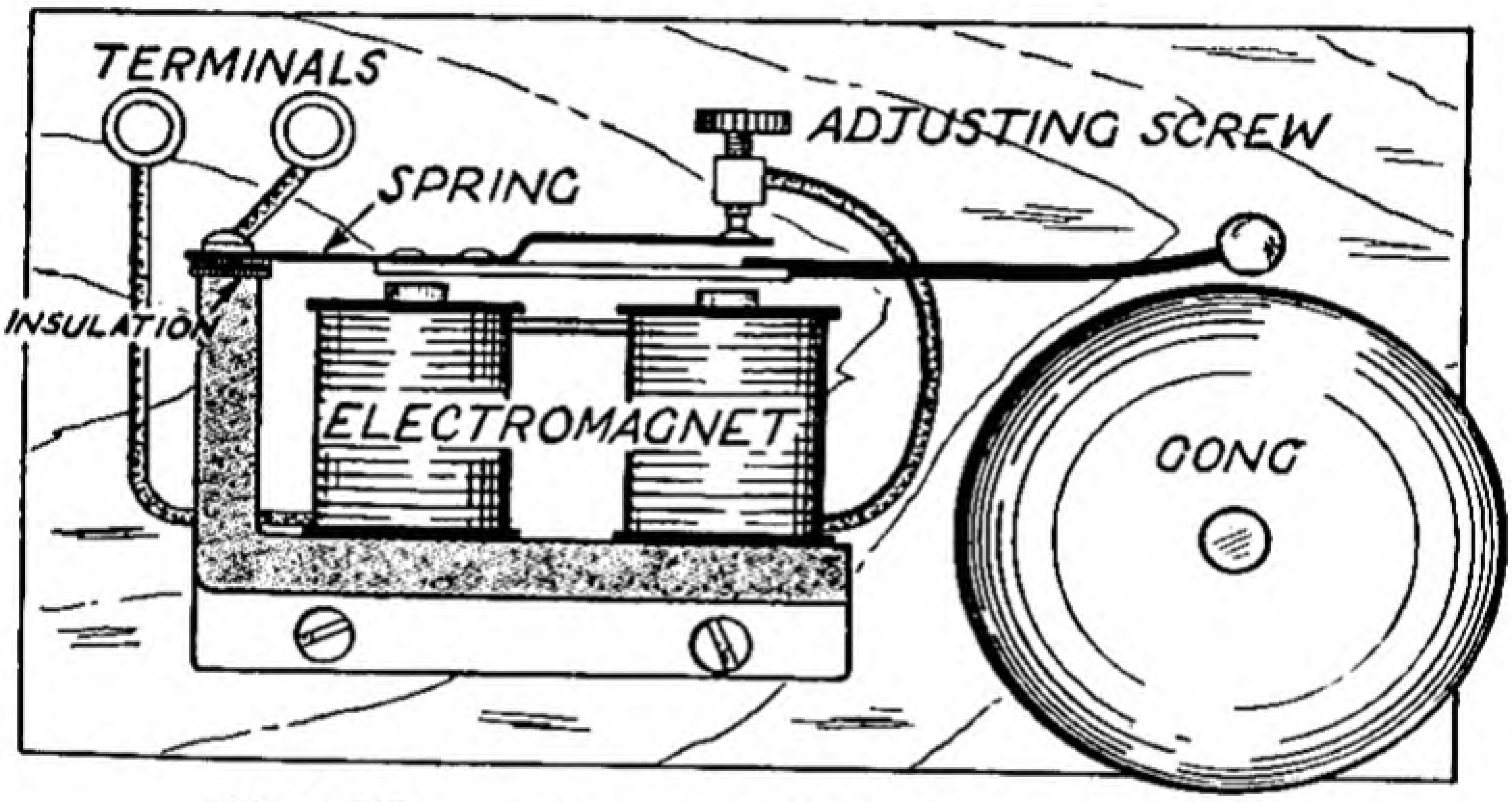


Fig. XII, 1.—The principle of the trembler bell

the alternations of current take place. The frequency of the supply, 50 c/s per second, is too great for the iron armature to follow the alternations exactly, but it will be set into vibration at its own natural frequency, as if it were a reed. The brass knob at the end will then strike the gong and set up a sound which is midway between a buzz and a ring.

This type of bell normally needs no maintenance but occasionally the gong, which is screwed down on to a central post, may become loose, in which case the hammer will not make proper contact with it and there will be either a very faint sound or no sound at all.

If the mains-connected type of bell is used, the mains circuits will be taken through the bell-pushes, which must be of a suitable type for operation at 240 volts. If mains circuits are applied to the very light and small bell-pushes used normally for battery circuits, there may be serious danger of electric shock, and in any case the contacts will

soon be badly burnt away by the arcing caused each time the bell-push is used.

In the lower-voltage types of bell circuits, whether alternating current or direct current, the only maintenance normally required apart from the bell itself is the occasional cleaning of the bell-push contacts. These are usually of very light construction and may become tarnished by verdigris or other corrosion. With the small voltages available to penetrate the film of dirt or corrosion, the bell circuit will be put out of action very easily through a defective bell-push.

It is possible to arrange for a number of bell-pushes to operate a single bell, and for a number of bells to be operated by a single push. In the case of hotels, and in some private houses, indicators are used to show which bell has operated (Fig. XII, 2). These take the form of small electromagnets included in the bell circuit, and having very

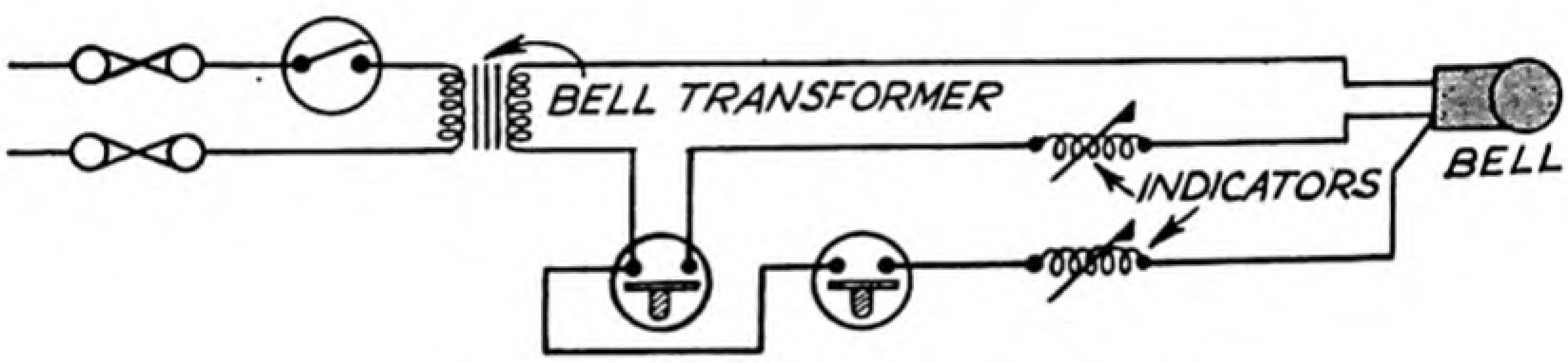


Fig. XII, 2.—Bell indicator circuit

light armatures, on which numbers may be painted. The armature is attracted towards the electromagnet when the bell circuit is energized, and so moves into or away from a window in the bell indicator. In this way the attendant can see which bell-push has been operated.

By means of suitable switching circuits, it is possible to arrange, for example, that all the bell circuits on a particular floor can be switched over at night to a central position, so that if any one of them is operated the night attendant is warned, and can then proceed to the floor concerned to see which indicator has moved. Indicators are of two kinds, one in which the swinging armature moves only as long as the bell-push is pressed (except for its natural momentum afterwards) and the other type in which it moves over and is held by a catch, giving a permanent indication that the circuit has been operated, until the catch is released by a manual resetting device.

Bell circuits may also have change-over switches fitted so that during the night hours, for example, a lamp takes the place of the bell, and a small relay may be introduced so that the lamp remains alight until the relay is reset.

development of the submerged repeater for submarine cables. The use of submarine cables for telephony had previously been limited to very short distances, as the physical characteristics of telephone lines are such that they could not be operated without repeaters at various stations along the length; and until the advent of the submerged repeater this had obviously not been possible.

The enormous cost and the complexity of the operation of laying a submarine cable means that everything used in connection with it must be of the highest possible reliability and must not need any form of maintenance for an indefinite period.

It has only been within the last few years that the ordinary electronic valve, as used in radio sets, has been considered to have reached a degree of reliability where it could be installed in an amplifier to be inserted in the submarine cable and then lowered, with the cable, to the ocean bed. The consequences of any failure can well be imagined. The power supply for the valves for submerged repeaters is fed into the cable itself, and as an example of what the submerged repeater has made possible in the way of long-distance submarine cable telephone use, the longest submarine telephone cable in the world, between Lowestoft and Borkum, in Germany, 200 miles in length, has been in operation since 1946 and has been entirely satisfactory.

Telephone cables, embodying a number of repeaters, which will have to face up to the enormous pressures in the deep oceans, are now being installed across the Atlantic.

Telegraphy, in its simplest form, consists in sending impulses of various lengths over an electrical circuit, and providing at the receiving end some type of appliance which will enable the signals to be understood. The basic telegraph circuit will therefore comprise a switch or key, a battery, a pair of wires to the far end, where there will be a bell, buzzer, lamp, or galvanometer. Depressing the key will send a current through the circuit, and the receiving operator can then note the signals, which will probably be sent by means of the morse code, in a series of long and short impulses. For two-way operation, a simple modification of the circuit, with a battery and receiving device at both ends, can be employed. As the impulses making up a telegraph circuit are distinguished one from the other only by the length of time during which the key is depressed, telegraph signals can be sent over a line having very poor electrical qualities, unlike telephone circuits, where leakage between lines, high resistance due to great lengths, and other electrical factors, may render telephone conversations unintelligible. The simplest telegraph circuit is a single wire joining the two points, using the earth as the return power. Repeaters

or relays may be introduced to amplify a weak signal, and unlike those needed for telephone purposes, these may take the form of simple electromagnetic relays. A weak signal on the incoming side operates the coil of a delicate relay, which closes the outgoing circuit on to a new source of power in the form of a local battery.

As with telephone systems, telegraph circuits can be used on the multi-channel system, and here even more channels can be provided by means of a given number of cables, since the frequency separation does not have to be so great.

Another form of telegraphic equipment is the teleprinter, now very widely used. Here a typewriter-like mechanism at one end is operated in the normal fashion, and a receiving instrument at the far end prints the message as if it was typed. When a typewriter key is depressed, holes are punched in a paper tape, corresponding to one or more of five positions. This tape then passes across a set of electrical contacts, which are made or not according to whether there is a hole in the paper tape at the point opposite the contact concerned. The arrangement of these contacts is such that they can send out, for the period corresponding to the sending of any individual letter, either current or no current, or positive current or negative current. In this way combinations of impulses can be built up so that the 26 letters of the alphabet, shift key operation, carriage return, and other typewriting requirements can all be signalled to the far end. Here the signals are interpreted so that each coded impulse is directed to an electromagnet which operates the appropriate type bar, and so prints the letter.

A complete network of "telex" circuits has been set up so that by dialling or by other means those who hire teleprinters from the General Post Office can be switched through to other teleprinter subscribers, and can thus send messages which are printed out automatically, and so provide a permanent record.

A branch of telegraphy which finds increasing use is that known as facsimile transmission. This is concerned with the sending of photographs or any other form of illustration by wire or radio, over any required distance, even right round the world.

The basic principle relies on the use of the photoelectric cell. The illustration to be translated is wrapped round a cylinder which revolves at a constant speed. A beam of light from a lamp is focused by means of lenses so that a point of light traverses every part of the illustration, in a spiral path. The light reflected from the illustration varies in amount according to whether that particular spot is light or dark. The reflected light is directed on to a photoelectric cell, whose output in

voltage is proportional to the light falling on it. The output from this cell is amplified, and then taken to the telegraph or radio circuit, where it takes the form of small pulses of energy, corresponding to the light and dark parts of the original photograph. At the receiving end these impulses are transformed into impulses of light, of varying intensity, by the use of a delicate electromagnetic device, which closes or opens a very fine slit in front of a lens. The light from a lamp is projected from the lens through this slit, and forms a point of light which plays on to a photographic paper, mounted on a cylinder revolving at the same speed as the original cylinder. In this way a spot of light of varying intensity traces out a path on the photographic emulsion, and affects it in such a way that, when developed, it will show an image corresponding to the original photograph.

CHAPTER XIII

SMALL GENERATING EQUIPMENT

WHEN considering the problem of providing electricity supply in isolated sites where no public mains exist, the degree of skilled attention required and available must first be ascertained, and then the storage problem must be dealt with. The voltage of supply also needs careful consideration. The fact must be faced that to provide a constant voltage (and, with a.c., a constant frequency) supply, to which mains consumers are accustomed, either a certain degree of skilled operation is necessary or else considerable expenditure in the automatic control equipment will have to be incurred.

If there is to be no storage by way of accumulators, the plant will have to be either left running permanently (which is only possible, for economic reasons, in the case of small water-power plants) or else additional expenditure will have to be incurred again in providing automatic starting gear which will start up the engine when the first lamp or other load is switched on.

The three forms of prime mover most commonly used for small generating plants are the internal combustion engine (working on petrol or paraffin or as a diesel engine); the wind generator; or the hydro-electric plant.

The diesel engine is nearly always chosen for generating plants other than the very smallest sizes, i.e. above about 3 h.p. or 4 h.p., where the petrol engine is used. Below this size there are a number of automatic-start plants in which the added expense of the relay for providing automatic starting is offset by the abolition of a large storage battery. In these plants the ordinary type of motor-car starter battery is used, and when the plant is at rest it is connected across the mains, which, in small plants of this type, operate at 12 volts or 24 volts, and will provide for lighting only, using car headlight-type bulbs. When any load switch is closed, so that a minimum current of about 40 watts is drawn from the battery, this current flows through a

relay coil which causes certain contacts to close or open. These auxiliary switching operations include the removal of the earthing connection from the engine ignition circuit, and the closing of the battery on to the dynamo in such a way that this runs as a motor and starts the engine. A time-delay device, incorporated in the relay, ensures that the engine has had sufficient time to start and to run up to speed before the connections are altered, by means of a second relay, so that the motor becomes a generator and supplies the load. It then sends small charges into the battery, through a cut-out in the normal way, so that the battery is always ready for use. Safeguards are arranged so that if the engine fails to start after a predetermined period, the battery will cut-out and so will not become completely run down. Automatic governing is also provided to ensure reasonably constant voltage.

When the last load has been removed, the relay falls off and in doing so applies the earthing switch to the ignition circuit, so stopping the engine, the cut-out preventing the battery from discharging back into the generator.

Small automatic sets may, if required, operate on a.c. In this case a permanent magnet alternator may be provided, or else a small exciter is built in and driven on the main shaft. This has the advantage of allowing for 240-volt equipment (which is standard for ordinary mains use) to be employed, but exact frequency control cannot normally be expected.

Automatic running of a small generator tends to be inefficient as the set will run very lightly loaded, and consequently inefficiently, for a considerable proportion of its total time. This will mean that the fuel cost for the current obtained will be high.

The automatic starting principle may be applied to larger sets and where a storage battery is fitted arrangements may be made so that the generating set cuts-in when the load reaches a certain predetermined value. This is achieved by means of a relay, the coil of which carries the main current and which is biased against a spring, so that its contacts will not close, to energize the starting circuits, until a certain current value is reached.

Maintenance of a petrol or diesel electric generating set is largely a mechanical matter, and the maintenance of the engine itself follows the lines adopted by garages for normal internal combustion machine maintenance. Maintenance of the electrical side is largely concerned with the battery and this aspect will be dealt with later. Normal maintenance of the commutator and brush gear is required, perhaps every six months, and lubrication of bearings must also be carried out periodically. The contactors and relays will occasionally need their

contacts cleaning with very fine emery cloth, after which they should be wiped with a non-greasy cleaning fluid.

Battery Lighting Plants

Generating sets in which a storage battery is provided may be operated in several ways. If some degree of skilled attendance is available the main load may be taken by the battery at all times, the generator being run for fixed periods, perhaps once a day or even once

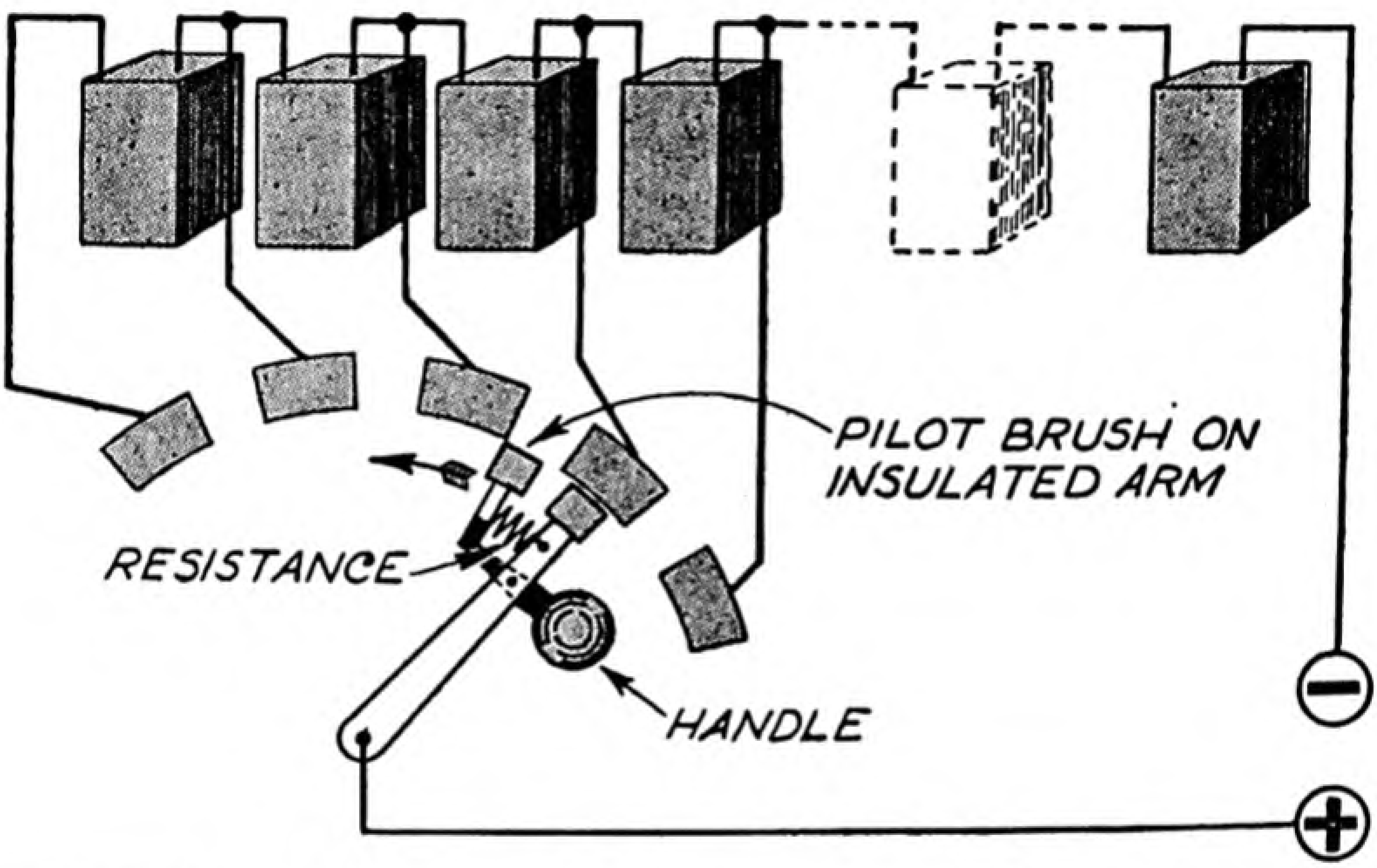


Fig. XIII, 1.—Tapping switch for voltage regulation in connection with batteries of accumulators

a week, to charge the battery. If this is done, there will be the need for end cell tappings to maintain the voltage of supply as the battery voltage drops. A tapping switch of a special type is provided (Fig. XIII, 1). If, say, six cells at the end of the battery were simply connected to studs over which a rotary arm were to pass connecting the outgoing lead to each of the cells in turn, either the whole supply circuit would be broken as the rotary arm left one stud to pass on to the next, or else, if it touched two studs at once, it would short circuit the cell connected between the two. This is avoided by the use of a rotary switch arm made in two parts, insulated from each other, and connected to each other by means of a suitable resistance which can carry for a few moments the short circuit currents plus the load current. As the double switch arm passes from stud to stud, the short circuit

resistance carries the current and thus avoids overloading cells or breaking the circuit.

End cells must be specially cared for during charging and discharging, since there is a danger that they will be seriously overcharged. One method of avoiding this is to have a relatively large number of tappings at both ends of the battery, so arranged that no one cell is heavily overcharged. If a particular cell, at the extreme end of the battery, is brought into service only when the battery voltage has fallen to the lowest point, and yet receives the full charge every time the engine is put on load, it is obvious it would be charged to a much greater degree than the other cells.

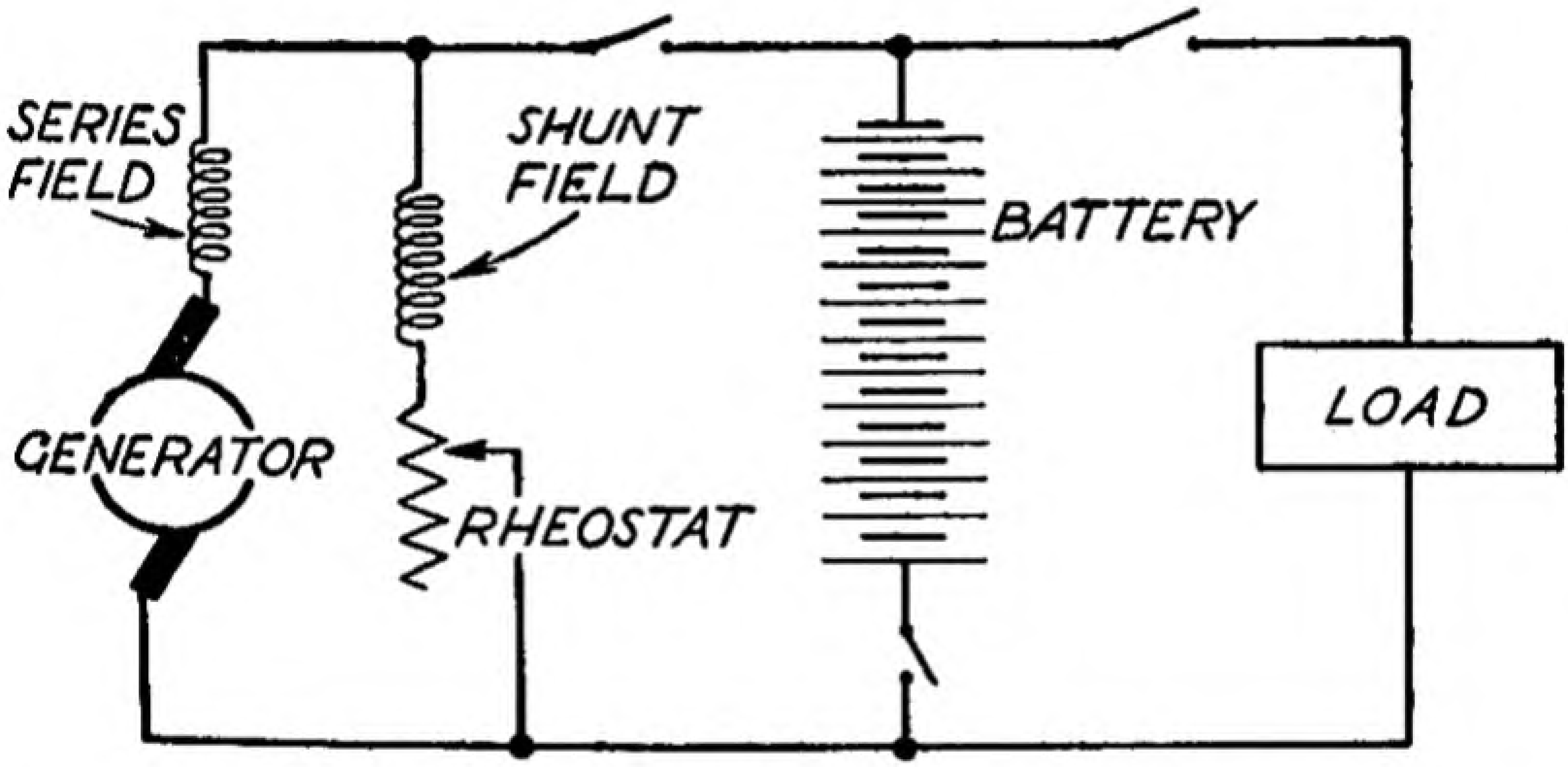


Fig. XIII, 2.—The "floating battery" circuit

Another method of using a medium-sized engine generator plant is to operate it on the floating battery principle (Fig. XIII, 2). Here the battery is permanently connected across the generator, the engine governor and the voltage regulator being so arranged that the battery is not normally called on to supply any load, which comes from the generator as required. The battery receives a very small charge and only discharges at times of (*a*) severe and brief peaks, and (*b*) very light load, when the generator is shut down. For peaks, the battery is especially useful as it enables the generator to meet momentary or short-term overloads which it could not otherwise accommodate; thus a smaller generator can be used than would be the case if it had to operate without a battery. Moreover, a single unit only can be employed, as the battery can carry the load during maintenance periods or breakdowns. The economic balance sheet here hinges on

the cost of the battery and its maintenance, as against the cost of a standby generating unit.

Wind Generation

Wind power may be used to supply small installations. It is estimated that the average wind speed over most of the British Isles, particularly the coastal areas, averages 15 miles an hour throughout the

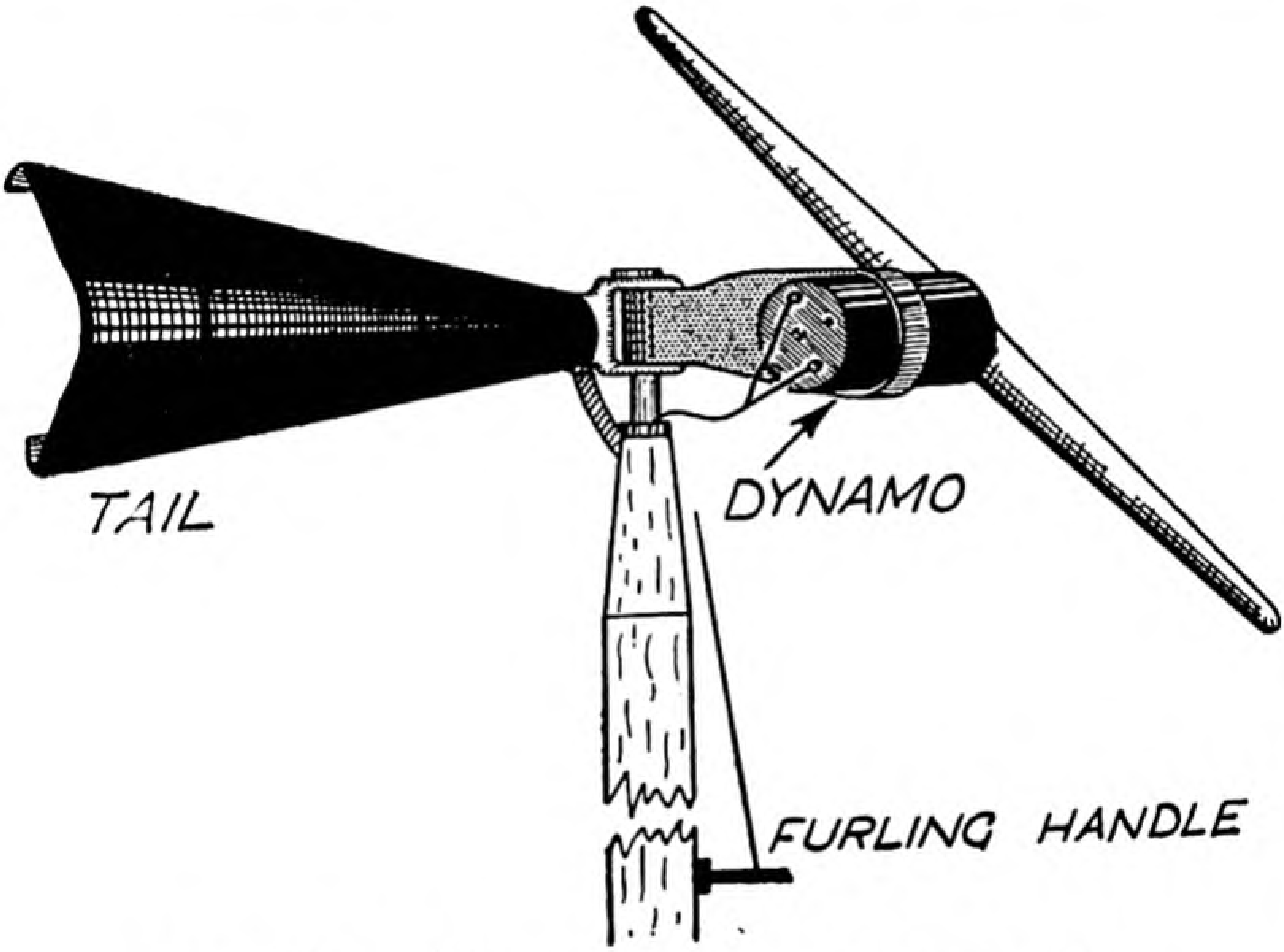


Fig. XIII, 3.—Elements of a small wind generator

year, and a 1-kilowatt windmill may be expected to produce about 4,000 units a year. Thus even a very small unit might be expected to provide reasonable lighting current for a dwelling house, although it would of course be necessary to provide storage batteries.

The usual type of windmill employs a 12-volt dynamo of the type usually used in cars, placed at the top of a mast and driven by a six-foot, twin-bladed propeller (Fig. XIII, 3). It is mounted on a mast of 35 to 45 feet in height, and a tail-fin brings it into the wind. It will start to operate with a wind speed of about 12 miles an hour, and will develop full output at 20 to 25 miles an hour. It is connected, through a cut-out, to two 130 ampere-hour car-type batteries, although

any number of additional batteries, in multiples of 12 volts, may be connected-in so that at times of prolonged calm power may be still obtained, the batteries being charged continuously during windy periods.

As there is no "fuel" cost, wind power is obviously an attractive method of generating electricity, but the drawbacks are that only small amounts of power can be obtained from a single windmill, unless it is to become a major engineering feat (as mentioned in Chapter II). In this case it has to be strong enough to withstand gales, and so the capital cost tends to rise.

Special care should be taken with wind power batteries, as they tend to become subjected to severe overcharging and heavy discharging, due to the variable nature of wind power.

Small Hydro-electric Plants

Small hydro-electric plants are the most attractive of all forms of generating electrical energy. Obviously they can only be operated where suitable streams exist. The type of turbine to be used depends on the head available, i.e. the total drop from the supply level to the tail race when the water is not running. Some form of dam usually has to be erected across the stream, and the water then piles up against it and is allowed to flow out through a controlled opening. It is then usually carried in a pipe to a lower level, where the turbine is installed, and after passing through the turbine it runs away into the tail race.

The possibility of providing power from a given stream can be estimated by the simple formula

$$P = \frac{Q \times H}{600} \text{ b.h.p.}$$

where P is the turbine output in brake horsepower, Q is the rate of flow of water in cubic feet per minute and H is the net head in feet.

To estimate Q, the rate of flow, several methods are available but the simplest is to plumb the bottom across a section of the stream and thus arrive at an idea of the sectional area of the water flow (Fig. XIII, 4). Then, by dropping floats into the stream some distance upstream from the measured section, and checking exactly the time taken by a float to pass over a given distance, the flow may be ascertained by multiplying the area of the section of water channel (in square feet) by the current in feet per minute. The friction on the bank and other factors mean that the measured figure should be reduced by some-

where about 40 per cent in the case of streams with irregular banks, while if a wooden trough is used to bring water from a stream to a prepared head race, the reduction in flow should be of the order of 15 to 20 per cent.

The net head should be calculated by first taking the gross head, from the still water level at the dam to the tail race, and then subtracting 15 to 20 per cent for pipe friction according to whether the pipe is long in relation to the head, as the slope may be severe or gentle.

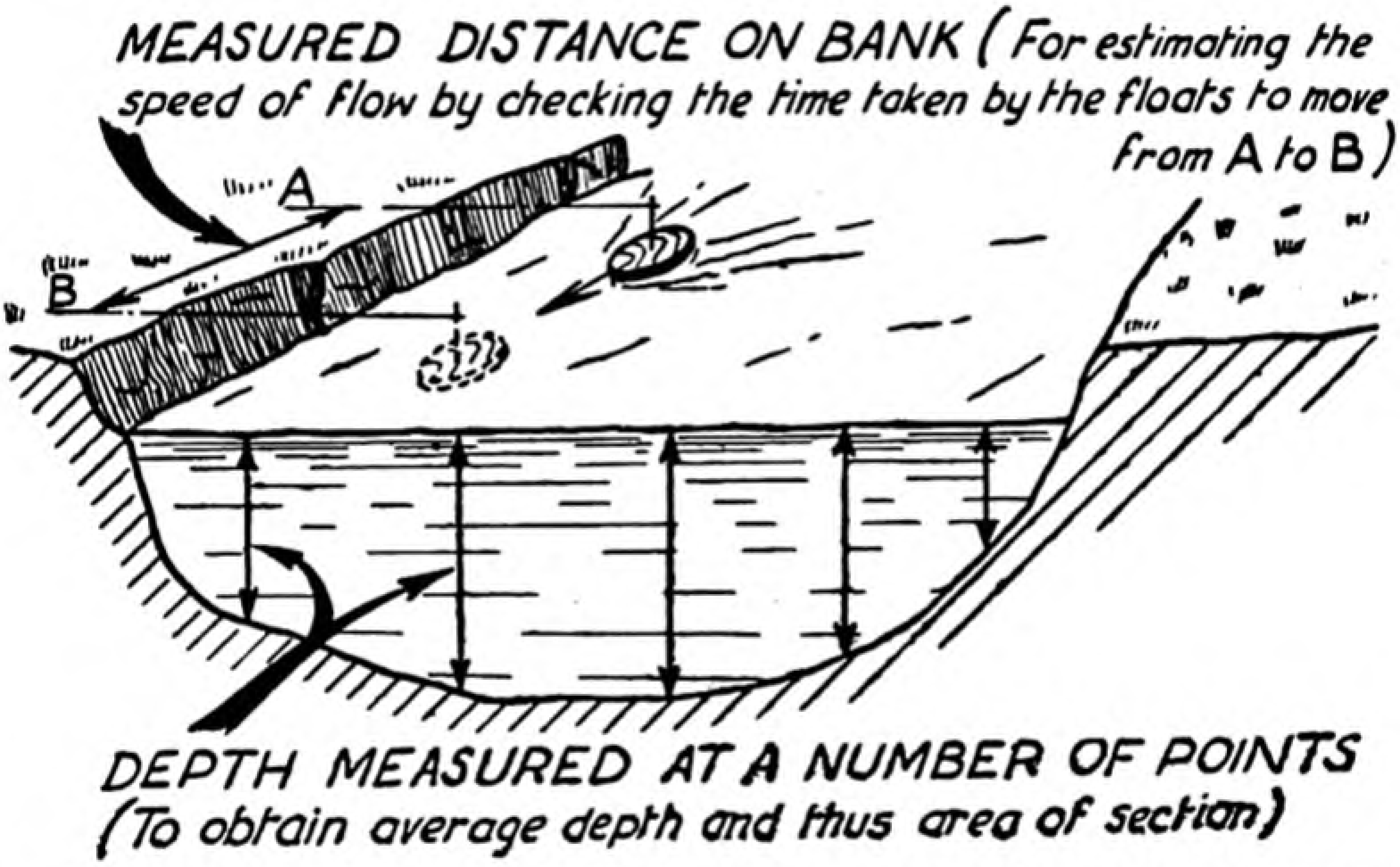


Fig. XIII, 4.—Method of obtaining an approximate measurement of the flow of water available for hydro-electric purposes

The simplest type of turbine for very low heads of up to 10 or 20 feet is the open-type Francis reaction turbine, which is mounted in an open concrete chamber and drives the generator by means of a belt and pulley, or through gearing (as the turbine speed is likely to be too low for efficient operation of the generator). For higher heads the closed-in reaction turbine is used; and for higher heads still, of the order of 100 to 500 feet, the Pelton wheel, in which a jet of water from the pipe line impinges in buckets mounted round a cased-in runner, is usually employed (*see* Chapter II and Fig. II, 7).

Small hydro-electric plants can be left to run entirely unattended for very lengthy periods. For the smallest units, very simple governing equipment is all that is needed, the governor taking the form of a centrifugal arrangement in which weights are revolved by the shaft

and fly out against a spring, in doing so operating a linkage which closes or opens the guide vanes admitting water to the runner. If the turbine is driving a d.c. generator, exact speed control is not of the greatest importance, and the output voltage may be controlled by means of the voltage regulator acting on the generator field. If a.c. operation is required, and careful control of frequency is necessary, the governor will usually be of a more complicated type in which oil pressure is used to actuate servo-motors controlling the guide vanes.

For the Pelton wheel type a jet deflector is used for governing. It acts by deflecting a portion of the jet away from the wheel if the speed increases.

Automatic starting and stopping of hydro-electric sets may be carried out by suitable relays so that motor-operated valves shut off the water or close the guide vanes. In view of the fact that there is no "fuel" cost, however, and that a well-constructed hydro-electric set does not suffer any injury by continuous running providing the lubrication arrangements are suitable, such sets may be left running continuously and taken off load simply by opening the load switch.

Maintenance of the water-wheel takes the form of inspection at least once a year to make sure that erosion has not seriously affected the edge of the blades or buckets. If gritty water is being used, this may constitute a serious problem, and one solution is to arrange for the leading edges to be given a welded coating of stainless steel, which has a high degree of resistance to this type of damage.

One of the pitfalls to be avoided when inaugurating a small hydro-electric set, which is to be the sole source of electrical energy for a particular installation, is that the stream may have provided adequate water flow for the past two or three years and then may suddenly come on a drought period when no supply will be available. Thus records as far back as possible should be consulted. There is also the question of the provision of adequate means for relieving flood water, which may reach disastrous levels only once in perhaps ten or fifteen years. Sluice gates or valves, to allow the water to bypass the hydro-electric plant, are always necessary, and should be of ample dimensions.

Battery Maintenance

All these generating plants are likely to involve the use of batteries either as the main battery for supplying the load after being charged from the engine or as the starting battery. Thus the care of batteries is of vital importance.

To give an indication of typical sizes of batteries used, a 1 kW independent generating installation may employ a 25-volt battery, having 13 or 14 cells of 200 ampere-hour capacity, while a 5 kW set with 110-volt supply system may employ 54 cells with a 240 ampere-hour rating, at the 10-hour rate. The battery is usually designed, if it is used for the main load, to carry half the total load for about 10 to 15 hours.

The usual type of batteries employed are lead-acid accumulators of the sealed-in type, and they are mounted on wooden racks perhaps in two rows one above the other. It is necessary to provide for adequate access for maintenance, and glass cell batteries allow for easy inspection of the plates. The battery room should have a floor that will not be injured by spilling acid, and care should be taken that there is adequate ventilation, as the gases evolved during charging are liable to cause explosion if trapped in a closed room.

The equipment needed for the maintenance of batteries includes a cell voltmeter and a hydrometer (*see* page 204). The specific gravity of each cell in every battery must be checked before every charge and an hour after the charge has ceased (if the battery is regularly charged at one operation), or at least at monthly intervals if the battery is of the floating type.

If a particular cell is found to be weak, by having a lower specific gravity than the others or because it does not gas when being charged, it should be carefully inspected and it may be seen that some metallic connection exists between the positive and negative plates. This might arise through some object inadvertently dropped into the battery, or perhaps through the breaking away of part of the lead grids on the plates. In old batteries a deposit may form in the bottom of the cells and if this has built up to a level where it short circuits the plates, immediate steps must be taken to have it removed. Each battery maker provides a card of instructions for the working of the battery, the specific gravity of the acid when charged and discharged, and the recommended voltages per cell at various states of charge and discharge. This card should be carefully preserved, as it is vital the user should follow its instructions if the battery is to have its full length of life.

Trickle Charging

An aspect of battery operation that frequently applies to private installations is trickle charging in which the battery is connected to a small rectifier unit which provides a continuous "trickle" of current,

perhaps of one-quarter to one-half of an ampere. This current is *not* meant to charge the battery but to replace losses which occur when the battery is on open circuit. If a battery should be charged in this way, i.e. at a very much smaller current than normal, the result would be a soft deposit on the plates which would easily fall away, with the result that the battery's working life would be materially shortened.

Trickle charging, therefore, should be carefully kept to its proper use, which is to maintain a battery healthy when it is not being used; if some small indicating lamp or some similar load is connected up so that it is always alight, its load must be added to the normal trickle charge current.

Wiring

The wiring to be employed in isolated electric generating plants needs careful planning. In the case of ordinary town mains wires, the voltage of 240 volts means that the current required for most appliances is low in relation to the smallest size of wiring likely to be used, and thus the voltage drop caused by the resistance of the wire itself is usually negligible. As an example, a 60-watt lamp at 240 volts takes almost exactly ¼ ampere and the voltage drop in a 100 foot run (there and back) of the commonly used 3/·029 cable is slightly greater than 1/10 of a volt. If a 60-watt lamp is operated on a 12-volt circuit, the current taken is 5 amperes, and the voltage drop under the same conditions would be a little more than 2 volts. Thus if a windmill, for example, is situated on a hill at some distance from a farmhouse, the voltage drop must be taken into account in choosing the size of wiring, and wires which are much heavier in cross section than those normally employed for mains voltage circuits will be found necessary.

TABLES

Power Consumption of Electrical Appliances

(*Approximate figures*)

Lamps:
15 to 150 W (rarely more)
Irons:
Domestic size: 500 to 750 W
Industrial: 750 to 1,000 W
Kettles:
2 pints: 450 or 650 W
3 pints: 1,000 to 1,500 W
Hot Water Tanks and Wash Boilers:
8–10 gallons: 3,000 W
Immersion Heaters:
2,000 and 3,000 W
Geysers:
3,000 and 5,000 W
Warming Plates:
400 W (smaller sizes)
1,500 W (larger sizes)
Hot Plates and Boiling Rings:
500 to 4,000 W
Food Warmers:
Typical size: 400 W
Toasters:
500 W (small size)
1,000 W (large size)
Grills:
8 in. × 6 in.: average 750 to 1,000 W
12 in. × 18 in.: average 3 to 3·5 kW
Ovens (as on domestic cookers):
Average loading: 2 to 3½ kW
Urns:
1 gallon: 1,000 W
3 gallons: 1,500 or 1,750 W
6 gallons: 3,000 W
Towel Rail:
Average 250 W
Tubular Heaters:
Average: 60 W per foot
Certain cases: 80 W per foot
Radiant Fires:
1, 2 or 3 kW
Washing Machines:
Without heater: 500 W
With heater: 3,500 W
Refrigerator:
250 W
Vacuum Cleaner:
Average 250 W
Hair Dryer:
Average 500 W
Soldering Iron:
½ lb.: 60 W
2 lb.: 250 W
Small Motors as for drills:
Up to ½ in.: 250 W
Grinding Wheel, 6 in.:
750 W
Radio Set:
Average table model: 80 W
Television Set:
average 180 W

NOTE: On d.c. circuits, and on a.c. circuits containing resistance only (as in apparatus equipped with heating elements), the following approximate figures may be taken to indicate current consumption:

At 100 V, 1 kW = 10 amps
At 200 V, 1 kW = 5 amps
At 210 V, 1 kW = 4·76 (say $4\frac{3}{4}$) amps
At 230 V, 1 kW = 4·34 amps
At 240 V, 1 kW = 4·16 amps
At 250 V, 1 kW = 4·0 amps

APPROXIMATE CURRENT RATING OF MOTORS

	D.C.			*A.C. Single Phase*	*A.C. Three-Phase*			
Horsepower	110 *V*	250 *V*	440 *V*	240 *V*	346 *V*	400 *V*	415 *V*	440 *V*
1/20	0·9	0·4	—	1·5	—	—	—	—
1/8	1·8	0·8	—	1·5	—	—	—	—
1/4	3·0	1·3	—	2·7	—	—	—	—
1/2	5·6	2·5	1·4	3·6	—	—	—	—
1	10	4·5	2·5	6·3	2·1	1·9	1·8	1·7
2	19	8·4	4·7	11	4·0	3·5	3·4	3·2
5	40	17·6	10	24	9	7·8	7·4	6·7
10	79	34·5	20	46	16·8	14·5	14	13·2
20	155	68	38	37	32·4	28	27	25·4
50	380	167	94	—	89	69	66·5	63
100	750	330	185	—	158	137	132	125

NOTE: The above table gives approximate values for motors of average power factor and efficiency. Individual motors may vary slightly—for example, capacitor motors would have smaller current ratings than the smaller sizes of single-phase induction motors quoted above.

Fuses

Approximate Fusing current Amps	*Copper*		*Tin*		*Tin-Lead Alloy or Lead*	
	Dia. in.	*S.W.G.*	*Dia. in.*	*S.W.G.*	*Dia. in.*	*S.W.G.*
1	·0020	47	·0076	36	·0084	35
2	·0036	43	·0116	31	·0136	29
3	·0044	41	·0148	28	·018	26
5	·006	38	·022	24	·024	23
10	·01	33	·036	20	·040	19
15	·0124	30	·044	—	·048	18
20	·0156	—	·052	—	·064	16
30	·020	25	·072	15	·080	14
50	·028	22	·096	—	·116	11
60	·032	21	·110	—	·128	10
80	·040	19	·134	—	—	—
100	·048	18	·152	—	—	—

Current Ratings of Cables

Cables from 1/·044–7/·029 bunched and run in conduit, with approximate lengths for 1-volt drop

Size of cable	*4 Cables**		*8 Cables**	
	Current (amps)	*Length of** run (feet)*	*Current (amps)*	*Length of** run (feet)*
1/·044 ..	5	36	5	36
3/·029 ..	5	47	5	47
3/·036 ..	10	35	8	42
7/·029 ..	15	34	12	42

* Four single-core cables or 2 twin, or 1 three-core.
Eight single-core cables or 4 twin, or 2 three-core.

** Lengths are lead and return for d.c. or single-phase a.c. or lead only for balanced 3-phase a.c.

Current Ratings of Cables—Contd.

Cables from 7/·036 to 61/·103 bunched and run in conduit with approximate lengths for 1 volt drop

Size of Cable	*C*		*D*		*E*		*F*	
	Amps	*Run (ft.)*	*Amps*	*Run (ft.)*	*Amps*	*Run (ft.)*	*Amps*	*Run (ft.)*
7/·036 ..	29	27	23	34	20	40	17	45
7/·044	38	32	30	41	27	45	23	54
7/·052 ..	45	37	36	46	32	52	27	61
7/·064 ..	56	45	45	57	39	65	34	76
17/·044 ..	65	49	52	61	46	70	39	84
19/·052 ..	78	57	62	73	55	82	47	95
19/·064 ..	102	65	82	84	71	97	61	113
19/·083 ..	147	74	118	96	103	110	88	129
37/·072 ..	189	78	151	103	132	118	113	137
37/·083 ..	229	79	183	103	160	118	—	—
37/·103 ..	298	78	238	103	—	—	—	—
61/·093 ..	358	72	286	96	—	—	—	—
61/·103 ..	413	66	330	86	—	—	—	—

Column C: 2 single cables.
" D: 4 single cables or 2 twin.
" E: 6 singles, 3 twin, or 1 three-core or four-core.
" F: 10 singles, 5 twin, or 2 three-core or four-core.

Lengths given are lead and return for single-phase a.c. or (for columns D, E, F only) lead only for 3-phase balanced a.c.

Current Ratings for Flexible Cords

Stranding	*Nominal Area (sq. in.)*	*Max. Current (2-, 3- or 4-core)*	*Max. Weight allowable on a twin cord*
	sq. in.	*amps*	*lb.*
14/·0076	·0006	2	3
23/·0076	·001	3	5
40/·0076	·0017	5	10
70/·0076	·003	10	10
110/·0076	·0048	15	10
162/·0076	·007	20	10

GLOSSARY

a.c.—commonly used abbreviation for alternating current.

accumulator—alternative word for secondary or storage battery, i.e. battery in which energy is first received and then given out later, when required.

aerial—some form of conducting material arranged for the transmission or reception of high-frequency waves used in connection with radio-telephony, radio-telegraphy, television, and radar and other direction-finding devices.

alternator—a machine for generating electric current on the a.c. principle.

ammeter—instrument for measuring current, in amperes.

ampere (abbreviation—*amp.*)—the unit in which electrical current is measured.

ampere-hour—the unit of quantity of electricity, commonly used for expressing the capacity of storage batteries.

ampere-turns—the expression used to measure the magnetic effect of a coil, expressed as a product of the amperes passing through multiplied by the number of turns in the coil.

amplifier—an apparatus whereby a weak input current can influence a stronger current on the output side so that the larger current varies in sympathy with the weaker current.

amplitude—the peak value of a varying quantity, such as a voltage or a current.

anode—the positive pole of a piece of electrical apparatus; in the case of an electro-chemical cell receiving current, the pole at which the current enters; in the case of a primary cell, the pole at which the current leaves.

arc—the state produced when current flows between two metallic or other solid electrodes separated by a gap in air, gas, or in an exhausted vessel.

armature—1. In the case of a relay or similar electromagnetic device the moving portion which is attracted to the poles when the device is energized.

2. In the case of an electric motor or generator the revolving portion, which is usually wound with insulated wire on a laminated iron former, the wire being connected to brushes or slip rings.

The word is also applied to the stationary part of those machines where the windings in which current is induced are stationary.

asynchronous machine—on alternating-current circuits rotating machines run

either at a speed rigidly linked with the supply frequency or at some other speed. The first are known as synchronous machines and the second as asynchronous machines.

audio-frequency—the frequency of audible sound waves, which lie roughly between 25 cycles per second and 12,000 cycles per second.

auto-transformer—a type of transformer in which there is only one winding. With one terminal in common at one end, the two supplies are connected at different tappings along the length of the winding.

battery—a term used indiscriminately to denote primary and secondary cells.

bi-metallic devices—devices that depend for their action on the use of thin strips of metal, each made up of two pieces of dissimilar metals joined together and expanding unequally, so causing distortion and bending when heat is applied.

Board of Trade Unit—the legal name for the kilowatt-hour, which is the unit of electrical energy.

brake magnet—on electric meters, a magnet is arranged so that its field cuts the revolving disc and the resultant currents induced in the disc slow it down and stop it when the driving torque is removed, thus preventing the meter from continuing to register when the load has been switched off.

bridge—a type of circuit—of which the Wheatstone bridge is an example—used for measuring purposes, and relying on the principle of balancing the effects of one current against those of another.

brush—a fixed contact (usually of carbon, but sometimes of metal) which bears on to some form of moving contact. Typical examples are the brushes used in connection with the commutators of direct-current motors and generators.

busbar—the common conductors on a particular electrical system, to or from which all the incoming and outgoing supplies may be connected or disconnected by means of some form of switching apparatus.

bushing (or bush)—the insulating shroud through which electrical wires are brought in to a metal-encased enclosure.

cable—usually an insulated conductor, but also used for bare overhead conductors, strung on pylons.

capacitor—an arrangement of conductors and insulators which allows of the storing of an electric charge. The simplest example of a capacitor is an arrangement of two parallel plates separated by a small air-gap; a capacitor used to be called a condenser.

capacitor motor—a single-phase motor in which a capacitor is used to provide the out-of-phase connection necessary for the starting winding.

cartridge fuse—a type of fuse element in which the actual fuse itself is enclosed

in an insulating carrier, with metal contact pieces at the ends. It is sometimes equipped with an indicating device to show that the fuse has blown.

cathode (see *anode*)—in the case of an electro-chemical cell receiving energy, the negative pole by which the current leaves. In the case of a primary cell, the negative electrode. Also used in general to denote the electrode connected to the negative side of a circuit, as in a thermionic valve or a rectifier.

cathode ray tube—the tube used in television sets, and elsewhere in electrical engineering, in which a beam of electrons is projected against a screen coated with powder which fluoresces when struck by the beam, and so makes visual images able to be seen.

cell—an electro-chemical assembly, the typical cell being made up of an anode and a cathode immersed in an electrolyte, i.e. single unit of a battery.

charge—1. The quantity of electricity delivered to the conductor, as in a charged body such as one plate of a capacitor.

2. The amount of energy input to a storage cell.

choke—an inductance coil, i.e. a coil wound (sometimes on an iron former) to have a specific amount of inductance.

circuit—the path of an electric current or of magnetic lines of force.

circuit breaker—the term used in place of "switch" to denote large devices specially designed for breaking high-voltage, high-power circuits.

clock, electric—three kinds: 1. An electric motor drives the hands, the speed being in synchronism with the frequency of supply.

2. An electric motor winds the spring of a clockwork mechanism.

3. Electrical energy keeps a pendulum moving, a number of slave dials being operated by means of electrical impulses.

co-axial cable—a type of cable used for high-frequency work in which the principal feature is the use of the minimum possible amount of solid insulation, the conducting core being supported inside a tube by insulating spacers.

commutator—basically a device for reversing the flow of electric current; but more generally applied to the collector with which the rotating armature of a d.c. motor or a generator is equipped, and on which the brushes are brought to bear.

compound winding—a type of winding for electric motors or generators in which there is both a shunt and a series field winding.

conduit—term usually applied to steel or copper piping used to carry electric wiring, but also applicable to a trough or other similar groove for the same purpose.

contact—1. The general meaning of the term is that two conductors are sufficiently close together for current to pass between them.

2. That part of a switch or circuit breaker where the break in circuit is actually made.

contactor—type of switch or circuit breaker closely similar to a relay, in

which the action of an electromagnetic device causes the contacts to open or close.

control grid—in a thermionic valve, the grid that controls the flow of current from anode to cathode.

controller—a type of multiple-switching arrangement in which there is a number of positions selected by means of a handle and enabling, for example, a crane motor to be started up in either direction, speeded up and braked.

convection heater—a type of heater from which the heat is disseminated by currents of air which circulate, rather than by direct conduction or radiation.

converter—apparatus that changes current from one form to another. Examples are the motor generator, usually employed to change a.c. to d.c., or the rectifier. The same also applies to conversion from d.c. to a.c.

core—the iron on which the windings of a transformer, a motor, or a generator are installed, or to the frame of a relay. The core usually consists of a series of thin magnetic iron sheets insulated from each other.

corona—a luminous discharge which occurs on high voltage electric power lines.

current—the passage of electrical energy through a body. Current is measured in amperes.

current transformer—a device used to enable heavy currents to be measured by an ammeter only capable of measuring small currents, and consisting of a transformer with a small number of turns carrying the main current and a large number of turns supplying the instrument circuit.

cut-out—a term used mainly to denote a fuse, but applying equally to any device that will open automatically an electric circuit under predetermined abnormal conditions.

cycle—in a.c. terminology, the complete cycle created by one revolution of the coil in an elementary permanent-magnet alternator, in which the voltage rises from zero to full value positive, returns to zero, rises to full value negative and returns to zero again, thus completing the cycle.

delta connection—in a three-phase a.c. system, the arrangement whereby the phases are connected in triangular form. The opposite type of connection is the star or "Wye" (American).

demodulation—the removal from the high-frequency carrier wave, used in radio telephony, of the intelligence superimposed on it at the transmitter.

depolarisor—a chemical used in a primary cell to prevent the polarization of the positive electrode from interfering with the output of the cell.

detector—a simple type of instrument in which a coil of wire carries the current to deflect a compass needle.

detector circuit—the circuit used in radio receivers for demodulation (see above).

dielectric—similar to insulator, q.v. A substance that presents a high resistance to the passage of an electric current.

dimmer—a variable resistance, inserted in lighting circuits to dim the light output.

direct current—a current that always flows in the same direction, although its value may vary. Sometimes called "continuous current".

direction finder—radio equipment used to enable a ship or aircraft to ascertain its position, or to enable land-based equipment to locate ships or aircraft.

directional aerial—aerial array in which the radio-frequency waves are propagated in one particular direction.

discharge—1. The giving-out of the energy stored in a secondary battery or accumulator.

2. The passage of electric current through gases.

distribution system—electricity supply is usually considered under three headings—Generation, Transmission (the bulk transportation of energy, usually over long distances), and Distribution (the final aspect of supply to the consumer).

distribution board—the switchboard or fuseboard (usually on a consumer's premises) from which the final sub-circuits are tapped off.

dry battery or dry cell—a type of primary battery in which liquid electrolyte is replaced by an unspillable paste.

dry-plate rectifier (metal rectifier)—rectifying device in which the rectifying properties of certain metallic substances are used.

dynamo—nowadays used only loosely to describe a machine driven by a prime mover to produce electrical energy.

earth—connecting electrical equipment to earth means connecting it solidly and permanently to the general mass of earth so that it must be at the same potential as the earth, and therefore safe from danger from electric shock.

earth leakage trip or relay—a device for detecting faulty insulation of electrical equipment by indicating when a current is flowing from the live conductors to earth.

earth wire—the wire connecting the frame of electrical apparatus to earth. In the case of a 3-core flexible cable this wire is connected to the large "earth" pin on the plug.

eddy currents—currents induced in some solid conductor such as the iron core of a transformer by a varying magnetic field.

Edison screw cap—a type of screw cap for electric lamps, used in Great Britain exclusively for the smallest and the largest lamps, and in America for all lamps.

efficiency—the ratio of the output of an electrical machine to the input.

electricity—a form of energy, seen in action when electrons are transferred along a substance from atom to atom.

electro-chemistry—a branch of electrical engineering dealing with the interaction of electrical energy with chemical substances.

electrode—a conductor from or to which current passes to some other substance (*see* anode and cathode).

electrode boiler—a boiler in which the water itself forms the resistance, through which current is passed from electrodes suitably spaced. The heat generated by the passage of current heats the water.

electrolyte—the substance, usually a liquid, through which current is passed in an electro-chemical cell.

electromagnet—a magnet produced by allowing an electric current to pass through a coil surrounding a coil of iron.

electromotive force—a term largely synonymous with voltage, i.e. the force or pressure present between two conductors, which is available to force current through some intervening conductor.

electron—a sub-atomic particle carrying a negative charge. All atoms contain a central nucleus of positively charged protons and uncharged neutrons surrounded by a planetary arrangement of electrons moving in orbits around the nucleus. The passage of an electric current is set up applying some form of force which causes an electron from one atom to be detached and passed on to another atom, and so on throughout the conductor.

electronic devices—devices in which the passage of current takes place not through a normal solid conductor, but by means of a passage of electrons through a gas or in a vacuum.

electro-plating—a method for depositing metals on other metals by the use of an electro-chemical cell through which current passes.

electrostatic effects—effects due to the charge on a body without the passage of current.

end cells—the last few cells of a battery of accumulators, which are often switched separately for charging and discharging purposes.

excitation—the supply of current to the coil of an electromagnet, and in particular the supply of field current to a generator. In this case the current is usually supplied from a special auxiliary generator known as an exciter.

farad—the unit for measuring capacitance. In practice the farad is too large for most purposes, and the microfarad (1 millionth of a farad) is the unit most commonly employed.

fault—the accidental short circuiting of two live wires of opposite polarity; the earthing of a live wire normally not connected to earth; the breakdown of an insulator, etc.

feeder—an overhead line or cable used to carry energy from the point where it is generated towards the consumer.

field—a region subject to electrostatic or electromagnetic influence. In the case of generators the actual field winding which creates the flux across which the conductors are made to revolve or which itself revolves across the conductor.

field magnet—that part of a generator or motor on which is wound the field winding providing the exciting flux.

filament—in electric lamps, a fine wire known as the filament is made to glow white-hot by the passage of current, and so creates luminous energy.

flash lamp—a popular term for a portable electric lamp supplied with energy by means of primary batteries or accumulator.

fluorescence—the emission of visible light by certain crystals when excited by various forms of radiation: for example, fluorescent crystals that glow when ultra-violet radiations reach them.

flux—1. Magnetic. The total lines of magnetic force that reach an area under consideration. 2. In connection with light the luminous flux is the total amount of light reaching a particular area.

foot-candle—unit of illumination. The intensity of light given by a source of one standard candle at a distance of one foot, the surface illuminated being at right angles to the rays.

frequency—in a.c., the number of complete cycles per second.

furnace, electric—furnace in which an electric arc is used to heat the metal, or a furnace in which current passing through a coil near the crucible induces currents in the metal which in turn heat it up and cause it to melt.

fuse—a device consisting of a wire, rod or strip of special fusible metal inserted, in a suitable carrier, in an electric circuit so that the passage of a current greater than that normally admissible will cause the fusible element to melt, so breaking the circuit.

galvanometer—an indicating instrument consisting of a coil of wire within whose influence there moves a magnetized needle passing over a scale, the deflection being proportional to the current passing.

generator—a device used for converting mechanical energy into electrical energy, and usually applied to a d.c. machine as opposed to an alternator.

Goliath (or giant) Edison screw—the largest type of Edison screw lamp cap.

grid—1. The National Electricity Supply Network, since the map of the inter-connection of generating plants represents a gridiron. 2. The mesh inserted between the anode and cathode of a thermionic valve to control the flow of current.

harmonic—an a.c. voltage wave sometimes has superimposed on it voltage waves of other and higher frequencies and these are known as harmonics.

henry—the unit for measuring inductance.

hertz—the unit of frequency measurement (less widely used in Great Britain than on the Continent).

heterodyne—in radio receiver circuits, a locally generated frequency is sometimes superimposed on the incoming frequency to produce a third "beat" frequency and this is known as heterodyning.

high frequency—a loose term usually applied to frequencies of several thousands or millions of cycles per second. Very high frequency (V.H.F.) and ultra high frequency (U.H.F.) are also terms used in radio engineering.

high tension—the word tension is not now used officially to denote voltage, but the expression "high tension" persists, particularly to describe the batteries or supplies used in radio sets to provide the anode current, these being known as high-tension batteries.

high voltage—loosely employed to denote the distribution or transmission voltage, as opposed to the "low voltage" (usually 415/240 V) used to supply consumers. The terms E.H.V. and E.H.T. (extra high voltage or tension) are still occasionally used.

horsepower—the unit of mechanical power measurement. It equals 33,000 foot-lb. per minute, and its electric equivalent is 746 watts.

hot wire instruments—a type of measuring instrument in which the heating effects of the current cause the pointer to move across the scale.

hydro-electric plant—an electrical power station in which the prime mover is some form of water turbine.

ignitron—a type of mercury vapour rectifier tube.

Ilgner system—a method of supplying very large motors by means of motor generators equipped with flywheels.

immersion heater—a resistance-type heating element enclosed in a suitable case which can be immersed in the liquid to be heated.

impedance—in a direct current circuit only the resistance opposes the flow of current; in an a.c. circuit the effects of inductance and capacitance also tend to oppose the current, and these effects, combined with the resistance, produce a cumulative opposition known as the impedance.

indicator—a device used in electric bell circuits to show which bell has rung. It usually consists of an electromagnetic element, the coil carrying the bell current and the indicator flap being caused to move.

inductance—property possessed by a part of an electrical circuit by virtue of which the magnetic flux created when a current flows through the circuit is enabled to link with other parts of the circuit itself. In this way a varying current flowing through a circuit possessing inductance encounters a form of opposition to its passage, known as impedance.

induction—process whereby a voltage or a magnetic effect is produced in some body or material other than that from which the induction takes place. When a conductor is moved across a magnetic field (or when the

field moves or changes so as to "cut" the conductor) an electromotive force is created in the conductor by induction.

induction furnace—furnace in which heat is generated by the induction in the metal to be melted of eddy currents created by an external varying magnetic field.

induction motor—motor in which the a.c. supply is connected to the stator and currents are induced in the rotor by induction. The rotor may be short circuited, as in the squirrel-cage motor, or may be connected through slip rings to external regulating resistances.

inert cell—primary battery in which the elements are normally dry and will therefore keep unharmed for lengthy periods. The cell is activated by being filled with water.

insulator and insulation—an insulator is a substance through which it is very difficult or practically impossible to cause an electric current to pass. Typical examples are porcelain, rubber, etc. Insulation is the provision of suitable insulating materials to insulate a given conductor, for example, the rubber covering on flexible cables. Insulating tape is tape impregnated with some form of insulating compound used to make joints in the insulating coverings of cables, etc.

integrating meter—the normal domestic meter is of the integrating type, i.e. it registers the total quantity of energy consumed in a given time.

intelligence—in telecommunications and radio practice denotes the speech, music or code signals being transmitted.

isolator—link for providing physical disconnection between two parts of an electric circuit. Isolators may be operated manually when no current is passing, or may take the form of links which have to be unbolted when the circuit is dead.

kilo—prefix meaning "1,000 times", and commonly applied to kilovolt (1,000 volts), kilowatt (1,000 watts) and kilocycle (1,000 cycles per second).

kilowatt hour—1,000 watts for one hour (or 500 watts for two hours, or 2,000 watts for half hour, etc.); the unit of electrical energy, also known as the Board of Trade Unit.

lagging current—in an a.c. circuit inductance will cause the current to lag in phase behind the voltage producing it.

lamination—the cores of such a.c. electrical equipment as transformers and motors are usually made up not of solid iron masses but of thin sheets of iron, insulated from each other to minimize the losses due to eddy currents.

lead-acid accumulator—one of the two most commonly used types of secondary battery or accumulator, in which both positive and negative electrodes are made up of lead plates immersed in acid.

Leclanché cell—the most commonly used type of primary cell, made up in both wet and dry forms. The electrodes are of carbon and zinc immersed in a salammoniac electrolyte.

limit switch—a switch used for such purposes as preventing a crane from travelling beyond its safe limits. Usually consists of an auxiliary switch actuated by the crane, interrupting the current supply to the motor.

lines of force—to illustrate the effect of a magnetic field (or an electrostatic field) imaginary lines of force are drawn, and this is of great practical use.

liquid rheostat—a type of resistance made up of two electrodes immersed in an electrolyte, and so arranged that the resistance between them can be varied, usually by moving one of them away from the other.

live conductor, wire, rail, etc.—the word "live" is here applied in the sense that the conductor in question is connected to an active source of electrical energy.

load—the demand imposed on a generator by a particular piece of apparatus. The term is also used to denote the output of a power station or a particular generator.

loading coil—in telephony, coils placed at intervals along the length of a telephone cable to neutralize the effect of the capacitance, and so provide improved transmission.

losses—losses appear in electrical circuits in the form of heat in the conducting wires; heat in iron cores caused by the production of eddy currents; friction, in the case of rotating parts; and windage, with rotating armatures. There are also corona losses and other specialized forms of loss.

lumen—a unit for measuring light flux. One lumen is the amount of light which falls on a surface of 1 square foot in area, every point of which is 1 foot distant from a source of light of 1 standard candle power. (The surface must obviously be part of a sphere.)

magnet—a property possessed by iron (and a few other materials) which enables it to attract and repel other similar materials. The earth itself is a magnet.

magnetic pole—that portion of a magnet where the lines of magnetic force are assumed to enter or leave.

magnetic circuit—the path from the north pole of a magnet to the south pole through which the lines of magnetic force are assumed to run.

magneto—alternating-current generator, with a permanent magnetic field, used especially for providing the ignition circuits of internal combustion engines, and for telephone ringing purposes.

master switch—a main switch controlling a series of circuits, and so arranged that whatever the position of the individual switches the master switch can override them.

Megger—an instrument for measuring insulation. A hand-driven generator

sends current through the circuit under test, its value being read off on an indicating pointer.

megohm—a unit commonly used when measuring insulation resistance; equal to 1,000,000 ohms.

mercury arc rectifier—rectifier in which the fact that an arc (maintained in a closed vessel in which there is mercury vapour) will only conduct current in one direction is utilized.

mercury switch—a switch in which electrodes are sealed into an evacuated vessel containing mercury, the vessel being rocked so that the mercury flows over the electrodes and closes the circuit (or opens it when the vessel is rocked the other way).

microfarad—one millionth of a farad, the unit of capacitance. The microfarad is the most widely used unit for measuring capacitance.

microphone—instrument for converting sound waves into closely corresponding electrical impulses. There are two general forms—the carbon microphone used in the telephone transmitter, and the electromagnetic or crystal microphones (of various types) used in broadcasting.

milliampere—one-thousandth of an ampere.

modulation—the process of varying high-frequency carrier waves, emitted continuously from a radio telephony station, with the low-frequency impulses corresponding to the sound waves of which the intelligence to be transmitted is made up.

motor—machine for converting electrical energy into mechanical energy.

motor generator—device used to change one type of electrical energy into another. A motor driven from one source of electrical energy drives (mechanically) a generator providing the required alternative type of energy.

moving coil instrument—measuring instrument in which the moving element is made up of a coil carrying the current to be measured, and which moves between the poles of a magnet.

neon lamp—lamp of the gas discharge type in which there are two electrodes in an exhausted glass vessel containing only a small quantity of neon gas. The resultant glow has a characteristic orange colour.

neon tube—type of gas discharge lamp used in advertising, and operating broadly on the same principle as the neon lamp.

neutral point—in a three-phase a.c. system, the common connection point to which one end of each of the three phases on the generator or transformer is connected.

north pole—if a magnet is freely suspended one end will tend to swing towards the North Pole of the earth, and this is called the north pole of the magnet. The convention is that the lines of magnetic force leave the north pole and flow to the south pole of the magnet.

no-volt release—device fitted to the starter of an electric motor so that if the power supply fails the starter will automatically return to the zero

position, thus avoiding the application of full voltage for the motor if the supply is suddenly resumed.

ohm—the unit of resistance.

Ohm's Law—one of the basic laws of electrical engineering which states that in a d.c. circuit the value of the current varies directly as the applied voltage and inversely as the resistance.

oil circuit breaker—type of circuit breaker used on high voltage, heavy current circuits, in which the actual break is carried out under the surface of a mineral oil, which has the dual function of acting as an insulator and of quenching the arc.

oscillator—term usually applied in connection with the valves used in radio transmitters to generate the very high frequencies employed in such circuits. An oscillating or resonant circuit is employed to set the frequency.

oscillograph—a cathode ray tube, generally similar to that used in the ordinary television set but employed for measuring quantities such as transient voltages, etc.

out-of-phase—one a.c. voltage or current is said to be *in phase* with another when the zero points of the two waves exactly coincide and each attains its positive maximum in the same half period. They are *out-of-phase* when these conditions do not apply.

over-voltage (and over-current)—the terms usually applied to conditions in an electric circuit where the values of voltage or current momentarily or permanently exceed the normal.

paper-insulated cables—for high voltage cables, the most commonly used insulation is paper strips impregnated with a resinous compound.

parallel connection—method of connecting electrical equipment so that the same voltage is applied to all the items of equipment, but the current divides between them. (The opposite method of connection is the series connection.)

peak—term used for the maximum point in the curve representing a varying voltage current, etc., or the daily, weekly, monthly or yearly fluctuations of load.

In the case of the ordinary a.c. wave the peak value is 1·414 times the useful value.

The peak load periods in an ordinary supply system in Great Britain are between 7.30 and 8.30 a.m. all the year round, with a second peak between 4 and 6 p.m. in the winter months only.

period—time taken by a complete cycle in an a.c. system.

permanent magnet—a magnet made of hardened steel (or special magnetic alloy) in which the magnetism is permanently retained.

phase—in an a.c. circuit the generation of the voltage wave may be visualized as being due to the rotation of a single loop of wire between the poles of the magnet. One revolution sets up the complete cycle, and any particular position in this revolution is known as its phase. Thus if two separate coils and their voltage waves are under consideration, they may differ from each other by being out of phase by a certain number of degrees, known as the phase angle.

phase angle—see *phase.*

photoelectric cell—a type of thermionic valve made up of an exhausted glass envelope containing electrodes which have the property either of setting up a voltage when light falls on them, or of altering their characteristics when the cell is illuminated. Such cells (known popularly as "magic eyes") find very wide application in industry and also form the basis on which the talking film is operated.

phototelegraphy (*or facsimile*) *transmission*—the transmission of still photographs or drawings over a telephone or telegraph circuit.

piezoelectric effect—the property of various crystals of exhibiting a relationship between mechanical pressure on their surfaces and their electric state. This property is used to set up an oscillating crystal circuit as an absolute standard of frequency for radio transmission stations. The converse effect is used also in such types of apparatus as the crystal pick-up on radio gramophone tone arms, and in crystal microphones.

plate—1. The anode in a thermionic valve. 2. The conducting surfaces in a capacitor. 3. The plates of an accumulator.

pole—1. Term used rather loosely to denote one of the terminals of a generator, battery or other current producing device, or for one "side" of a two-wire mains supply. 2. That part of a magnet from which or to which the magnetic lines of force are assumed to flow. 3. The electromagnets which provide the excitation for a motor or generator, particularly when these are of the salient type.

polyphase—in a.c. circuits a single-phase supply is one created by a single loop of wire revolving between the poles of a permanent magnet. If more than one loop (the successive loops being disposed at various angles to the first one) revolves between the same magnet poles, and if these loops are connected together, the result is a polyphase system. The commonest example is the three-phase system, which is the most widely used form of electricity supply.

polythene insulated cables—for low voltage cables (and to an increasing degree for high voltage cables) a type of homogeneous plastic material, usually polythene, may be employed.

positive—that part of a voltage-producing device from which, according to the "classical" convention, the current leaves to traverse the circuit on its way to return to the negative part, or pole.

potential—a term used in general as an alternative to voltage, and indicating that some part of a circuit which possesses a given potential is capable of sending a current from that point, through a suitable conductor, to

a point at a lower potential. The term potential difference expresses the same idea.

potentiometer—an instrument for measuring potential differences.

power—the rate of using energy, measured electrically in watts.

power factor—the only useful power obtainable from an a.c. circuit is that which arises from the combination of the voltage with such component of the current as may be in phase with the voltage. In a d.c. circuit the voltage and current are completely in phase at all times, whereas in a purely inductive circuit on a.c. the current lags 90 degrees behind the voltage and is thus completely out of phase. In the first case the power factor is unity and in the second case zero. In any given a.c. circuit the power factor needs to be expressed (for example as 0·85) before the useful power can be appreciated. Low power factor means that a greater current is being carried through the mains than is necessary for the work to be done, and thus greater losses are incurred and in general the system is working inefficiently.

power factor correction (see *power factor*)—low power factor usually arises from the presence of considerable amounts of highly inductive equipment in the circuit, particularly electric motors. To correct the power factor, capacitors (which give rise to a leading current, compensating for the lagging current of the inductive equipment) are often installed. They may be mounted adjacent to the motors concerned or there may be a mains capacitor battery for the whole installation.

pressure—an alternative term for voltage or difference of potential.

primary cell—an electro-chemical cell capable of producing a voltage between its electrodes; thus it becomes a means of generating electrical energy, the chemical energy in the electrodes being turned into electrical energy in the external circuit.

primary winding—in a transformer the primary winding is that connected to the source of supply.

protective gear—apparatus arranged to protect an electric circuit against over-current, over-voltage or other abnormal conditions. The simplest type of protective gear is the fuse, but for more accurate and discriminative protection, relays are used to trip or switch out the main circuit breaker if a fault occurs.

radar—a general name for devices used to detect, over considerable distances, the presence of such objects as aircraft and ships. The basic principle is that of sending out short pulses of high-frequency energy from a beamed and sharply focused aerial system, and then receiving back the echoes which result when these pulses strike the objects to be detected.

radiator—apparatus usually made up of resistance wire mounted on a suitable ceramic former and heated by the passage of current. Heat

is given out by radiation, and also by convection as the heated air rises.

radio frequency—a loose term meaning the high frequency—usually of the order of hundreds of thousands to millions of cycles per second—used in radio transmission.

reactance—in a.c. circuits the "obstruction" to the passage of current arises not only from the resistance of the conductors but also from the inductance and capacitance of the apparatus in circuit. That part of this "obstruction" due to the latter elements is known as the reactance.

reactive current—in an a c. circuit the useful current is that which is in phase with the voltage. That component which is 90 degrees out of phase with the voltage, and is therefore not capable of doing useful work, is known as the reactive current.

rectifier—a device for changing a.c. into d.c. by allowing current to flow during one half cycle only, and blocking the flow of current during the remaining half cycle.

relay—a device whereby a very small current or small change in current in one circuit may be used to open or close a second circuit, usually one in which much larger currents flow. Relays are electromagnetic or electronic. A typical example of the use of a relay is the photocell which switches on street lighting when darkness falls. A current of less than 1,000th of an ampere operating on the relay enables it to control currents of many amperes in the lighting circuits.

repeater—in telephony and telegraphy an amplifying device.

resistance—the property of a material which opposes the flow of electric current. When current is forced through a resistance by the application of an electromotive force, energy is dissipated in the resistance in the form of heat.

resistor—the correct name for a device (previously known as a resistance) which has a fixed degree of resistance for some special purpose in an electric circuit.

resonance—a circuit is stated to be resonant when it has a natural frequency of oscillation. A piano wire is resonant in the sense that when struck it gives out a particular note in preference to other notes; and the resonant circuit—which is a combination of inductance and capacitance —is the electrical equivalent to a tuned wire or reed.

rheostat—an adjustable resistor.

ring main—a method of connecting main circuits so that they form a closed ring. In this way one particular section of the ring may be switched out without interrupting supplies to any point.

rotary converter—a special type of motor generator in which the two machines are combined into one, the input being a.c. and the output d.c. It has largely been displaced by the mercury arc rectifier.

rotor—the rotating portion of an electrical generator or motor.

rupturing capacity—the power which may be safely dealt with by a fuse or switch or other device for disconnecting an electric circuit on load.

salient poles—a type of construction in motors and generators, etc., in which the exciting poles are made up in the form of separate pole pieces.

secondary winding—in a transformer, the winding that is not connected to the source of supply.

selector—in automatic telephony one of the devices employed at the exchange to select the required subscriber's number.

selenium—element used in photoelectric cells because its resistance varies with the amount of light projected upon it.

self inductance—if a varying current passes through a coil, the change in magnetic effect as the current changes causes the lines of magnetic force to cut the turns of the coil itself, and thus set up an opposing voltage which is known as the E.M.F. of self-induction.

series connection—connection in an electrical circuit whereby the various parts of the circuit are so arranged that a single current passes through them all in turn. This is also known as cascade connection. The usual alternative is parallel connection, whereby the various items of apparatus are all connected separately to the poles of the circuit so that the current divides between them.

series motor—motor in which the field winding is in series with the armature winding. Most "universal" motors for use on a.c. and d.c. are of this type.

series-parallel control—control used on railway electrical systems whereby two (or more) motors are first arranged in series across the supply so that they receive less than full voltage, and are then switched into the parallel connection whereby each receives full voltage.

servo-motor—a special type of motor, used mainly in connection with remote control equipment, whereby a small current can cause a motor to change its position and so actuate some mechanical equipment. The motor acts in effect as a relay.

short circuit—usually applied to an unwanted and accidental direct path between the poles of a piece of apparatus so permitting the current to flow directly through the short circuit and not through the apparatus. In general a short circuit will result in heavy over-currents which will blow fuses or operate protective gear relays.

short waves—a loose term for high-frequency currents used in radio telegraphy, and generally applied in distinction to medium and long waves.

shunt—connection in which the current flows through the apparatus to be connected in shunt (i.e. in parallel) with the other apparatus in series. The shunt-connected motor or generator has the field winding in parallel with the armature winding.

A shunt is a device used to enable an instrument capable of dealing only with small currents to measure large currents. Included in the circuit is a resistance element across which there is a voltage drop corresponding to the current flowing, and this element is known as the

shunt. The voltage drop, which may be of the order of a thousandth of a volt, is the quantity measured by the instrument.

shunt motor—motor in which the field windings are connected in shunt (i.e. in parallel) with the armature.

sine wave—the shape of the normal alternating current voltage wave, the same as the curve known in trigonometry as the sine curve.

single phase—the basic form of a.c., in which two wires are used and in which there is no other voltage. Also applied to apparatus for use on this system, such as single-phase motors.

slip—in an induction motor the rotor does not necessarily revolve at synchronous speed, i.e. the speed corresponding to the frequency of the supply system. The difference between the actual speed and the synchronous speed is known as the slip.

slip ring—an insulated ring fixed on the shaft of a machine to provide contact between the rotating winding and a fixed brush bearing on the slip ring.

slot—a groove in the stator or rotor of an electrical machine into which the insulated windings are inserted.

small bayonet cap (*S.B.C.*)—the bayonet cap fitting used on lamps for motor-cars, etc., which is smaller than the bayonet cap used on normal domestic lamps.

small Edison screw (*S.E.S.*)—a screw-type lamp cap used, for example, on flash-lamp bulbs.

socket—the fixed receptacle into which a plug to supply electrical equipment is inserted. Usually known as a socket outlet.

solenoid—a coil of wire so arranged that when current passes it draws in an iron core, thus causing some form of mechanical movement to be initiated.

sound recording—methods of registering sound waves electrically, either by means of cutting a plastic disc, operating photographically on a film emulsion, scratching a film emulsion, or magnetizing a wire or a specially prepared plastic tape containing iron particles.

spark—a flash that occurs when a charged body is discharged, or when there is a momentary break in an electrical circuit.

spark gap—a controlled gap across which a discharge may pass either for safety reasons or to measure the voltage reached by a particular circuit.

spot welding—resistance welding in which pointed electrodes clamp two thin sheets to be welded together under great mechanical pressure; a momentary welding current is then passed, causing a weld at the point of pressure.

squirrel-cage motor—a very commonly used type of induction motor in which the rotor windings are short circuited, with no connection to the supply. The usual form has some similarity to a squirrel cage, since the transverse bars of which the winding is made up are riveted to end rings for short-circuiting purposes, and so form a circular cage-like structure.

star connection—used in a three-phase a.c. system; one end of each of the three windings is connected to a neutral or star-point.

star-delta starter—motor starter in which the motor windings are first connected to the supply system in star (giving a reduced voltage across each winding) and then in delta, giving full voltage.

starter—device used for starting a motor and generally so arranged that harmful excess current (which would pass if the full mains voltage were applied before the motor has had time to develop a reverse electromotive force) is avoided. Starters also usually contain protective devices, such as fuses, no-volt releases, etc. Associated devices are starting resistances, starting transformers, etc.

static charge—an electrostatic charge accumulated on a body, causing it to acquire a potential above earth.

stator—in electrical motors and generators that part which does not revolve and which carries windings.

storage battery—alternative name for the accumulator.

substation—an assembly of switchgear, transformers and control gear, usually enclosed to prevent unauthorized access.

superheterodyne method—a method of reception of radio signals in which a locally generated oscillation is made to "beat" with the incoming signal, thus producing an intermediate frequency signal which carries with it the intelligence brought in from the aerial.

supertension—a loose description of very high voltage.

supply system—system of transformers, switches and mains, which carries the energy from a generating station to the consumers.

surge—a travelling wave of high voltage set up in an electrical system when some disturbance has occurred, or perhaps induced in a system by a lightning flash.

switch—appliance for disconnecting and reconnecting an electrical circuit. Nowadays the term is confined to low voltage and light current circuits, and switches for several thousands of volts and some hundreds of amperes, such as those used in supply systems, are known as circuit breakers.

switchboard—a general term to denote an assembly of switches at one point, but also used to describe the low voltage control panels from which the mains high voltage switches are remotely controlled.

switch-fuse—an assembly of a switch and a fuse.

switchgear—A general term to denote circuit breakers and switchgear of all types.

switch-hook—cradle on which the ordinary telephone instrument rests and incorporating switches.

synchronism, synchronous—when two a.c. systems are exactly in step (i.e. when the elementary loops of wire revolving between the poles of a magnet, which may be considered as generating the voltage in each case, are revolving at the same speed and are at the same angle to the vertical at any given moment) the two systems are said to be in synchronism.

A piece of rotating apparatus which runs at a speed dictated exactly by the frequency of the incoming supply is said to be running at synchronous speed.

tap changer—a device for varying the voltage on a transformer winding by applying the incoming or outgoing supply connections to various taps brought out along the length of the winding.

Tap changing may be carried out while load is flowing by the aid of an on-load tap changer, but is more often carried out with the load disconnected.

telephone cable—a cable, usually having a lead sheath, specially designed for telephone circuits, and usually made up of single-strand copper wires with dry paper tape insulation, the wires being twisted in pairs, and pairs being twisted together to make quads. For high-frequency work co-axial tubes (see *co-axial cable*) are used.

teleprinter—instrument in which signals are conveyed from one point to another by operating a typewriter keyboard at the sending station, the signals being reproduced at the receiver on a machine like a typewriter.

thermal power station—a generating station in which the prime movers get their energy from some form of combustion of fuel (for example, the ordinary steam power station in which coal is burnt to create steam, or the internal combustion station).

thermionic valve—the correct name of the ordinary "wireless valve"; it consists basically of an exhausted glass vessel into which electrodes are sealed.

thermo-couple—instrument used for measuring temperature, and operating on the principle that when alternate junctions of a chain of dissimilar metals joined together are heated, a voltage is set up.

thermostat—automatic switch operated by temperature. The usual principle employed is the bending of a bi-metal strip owing to unequal expansion when heated; this bending is made to operate the switch.

third rail—a rail, mounted on insulators alongside the running rails, used in electric railway systems to provide current to the locomotives or motor-coaches.

three-phase—a very widely used a.c. system in which three separate circuits, joined together, are used. If the elementary alternator is considered in which a single loop of wire revolves between the poles of a magnet (thus setting up a single-phase voltage) a three-phase voltage may be considered as being set up by three such coils on the same shaft disposed at 120 degrees from each other all rotating between the magnet poles. If one end of each of the coils is joined together, the other three ends may be used as the three conductors of a three-phase system.

three-pin plug—a plug in which—in addition to the two wires for the poles

of the circuit—there is a third pin for an earth connection. There may also be three-pin plugs for three-phase circuits in which all three pins are "live".

three-way switching—an arrangement of tumbler switches such that a lamp or other circuit may be switched on and off from three independant points.

thyratron—a gas-filled thermionic valve having the property of acting as a switch since it will not conduct at all until a particular value of grid voltage is applied and it will then continue to conduct until the anode current again becomes zero.

time lag—an arrangement used sometimes on starters, relays and contactors so that the device cannot operate until a certain predetermined time has elapsed.

time switch—a switch actuated by an electric motor, by a simple clockwork mechanism or by a clockwork mechanism rewound by an electric motor and so arranged that a circuit or circuits may be opened and closed at pre-set times.

tough rubber-sheathing (T.R.S.)—a commonly used covering for flexible electric cables.

track circuit—a means whereby the railway signalman can ascertain whether a train is standing on a particular portion of the track, the track circuit usually taking the form of a circuit made between the two running rails, which are insulated from each other, by the short-circuit set up by the wheels and axles of the train.

transformer—an electromagnetic device whereby alternating (or varying) voltages may be transformed from one value to another. The transformer consists of an iron core in which a magnetic flux is induced by the current in one coil, and this flux cuts the turns of a second coil on the same core which may have more or less turns, thus setting up a voltage which is greater or less than the primary voltage.

transmission—electricity supply technique is divided into generation, transmission and distribution. Transmission may be compared with the wholesale handling of the product, and distribution with the retail side.

trembler bell—an electric bell in which the gong is struck by a hammer on the end of an armature which is alternately attracted electromagnetically to a core, and pulled away again by spring action when the circuit is broken.

triode—a thermionic valve in which there are three electrodes—the cathode, the anode and between them a control grid.

trip circuit—in large switchgear where the opening of the switch is not carried out by hand it is known as "tripping", since it is actually effected by upsetting the balance of a powerful spring-loaded mechanical linkage. This is usually carried out by energizing a trip coil or solenoid, through the trip circuit.

trunk line—in telephone practice, a cable connecting two exchanges.

tumbler switch—correct name for the ordinary domestic switch, used universally to control lighting and other circuits.

tuned circuits—a circuit containing a capacitance and inductance so arranged as to make it responsive to a particular frequency.

turbo-alternator—generating unit used in steam power stations, and consisting of a steam turbine directly coupled to an alternator.

two-way switch—an arrangement of switches whereby a lamp or other circuit can be controlled from two independent points.

ultra-violet rays—radiation, of a higher frequency than normal light, which cannot be seen by the eye. These radiations are used, for example, in fluorescent tubes to cause the crystals to fluoresce and so give out the light we are able to perceive.

ultrasonic waves—vibration in air or other substance of a frequency higher than that which we can appreciate as sound. Generated electrically, ultrasonic waves are used in testing and in therapy.

universal motor—a motor that can operate on a.c. or d.c.

valve, electric (see *thermionic valve*).

variable capacitor—a capacitor whose capacitance can be varied, usually by altering the physical distance between the plates.

vibrating reed instrument—instrument for measuring the frequency of an a.c. current by causing an electromagnet, excited by the current, to set a number of reeds into operation. The reed that vibrates most strongly will indicate the frequency.

video frequency—in television practice, the term employed to denote the frequency used to transmit the vision signals.

voice frequency—another term for audio-frequency, i.e. a frequency which is of the same order as that resulting from the translation of speech and music vibrations into electrical impulses; used to distinguish this portion of a radio circuit from the high-frequency section used for the carrier wave.

volt—the unit of electromotive force or pressure.

voltage drop—the fall in pressure across any particular part of an electric circuit; usually applied to the unwanted voltage drop in the conductors carrying the energy from the source to the apparatus at which it is required.

voltage transformer—a special type of transformer used in measuring high voltage values, where it is impossible to connect the instrument directly to the circuit. The voltage transformer gives an accurate relationship between the high voltage and a low voltage suitable for application to the instrument.

voltmeter—an instrument for the measurement of electrical pressure or voltage.

Ward-Leonard system—a means for controlling the operation of very large d.c. motors. The mains power is brought into an a.c. driving motor that drives a generator which in turn supplies the main motor, and control is effected by operating on the field circuits of the generator and the main motor.

watt—the unit of electric power; the product of volts times amps for d.c. circuits, and volts times amps times the power factor for a.c. circuits.

watt-hour—the unit of electrical energy; the most commonly employed multiple of this unit is the kilowatt-hour, i.e. 1,000 watt-hours.

watt-hour meter—an instrument for measuring the amount of energy consumed in a given period, i.e. an integrating meter. The ordinary domestic electricity meter is a kilowatt-hour meter.

wattmeter—an instrument for measuring the power flowing in an electric circuit.

wave band—one of the ranges of frequencies or wavelengths into which the frequency spectrum is divided. An example is the medium waveband used for Home Service broadcasting.

wave form—the shape of the curve representing the change of voltage with time in an a.c. circuit. Normally the wave form is that of a sine wave.

wavelength—the distance between successive positive crests of an electric wave.

welding, electric—a method of joining metal parts by heating them up at the point of junction by the passage of an electric current; or of applying metal by passing current from a welding electrode to the metal to be welded.

welding generator—a special generator for welding purposes.

welding transformer—a transformer specially adapted to provide the secondary voltages and currents suitable for welding purposes.

wet battery—primary cell in which a fluid electrolyte is used. (The "dry" battery is a wet battery with the electrolyte in the form of an unspillable paste.)

Wheatstone bridge—a circuit used for measurement purposes, so arranged that known resistors are balanced against an unknown resistor until a zero effect is produced on an instrument; the unknown resistor can then be evaluated. The bridge principle can also be used for many other types of measurements.

wind-driven generator—a generator adapted for being driven by a propeller. In the smaller types the generator is at the top of a mast; in the larger types the generator is on the ground and is driven either through gearing or by means of a column of air.

winding—the assembly of insulated conductors arranged in slots in a laminated iron frame which makes up the electromagnetic part of a motor, transformer or other similar apparatus.

X-rays—high-frequency electric impulses that are not deflected by magnetic fields and that can penetrate solid substances thus greatly assisting in medical diagnoses, and also enabling engineers to test the soundness of metal structures.

zero point—the point in the curve representing the voltage or current in an a.c. circuit where the value passes through zero on its way from maximum positive to maximum negative or vice versa.

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